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Finsbury Technical Manuals

GAS AND PETROLEUM ENGINES

A MANUAL FOR STUDENTS AND ENGINEERS

BY

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PREFACE.

SEVERAL years have passed since the publisher informed me that a second edition of this book was wanted. Owing to the rapid progress in the development of the internal combustion engine, and the extended use of cheap power gas and petroleum oil in large engines, considerable additions were necessary; and instead of adopting the easy but unsatisfactory method of patching up the old work, it was agreed that I should completely rewrite the whole.

The success of the first edition has encouraged me to prepare this new book with the original aim: to aid engineering students and engineers in studying Gas and Petroleum Engines, and the principles that underlie and control their action, so as to put the practical man in a position to test the performance of these engines, and to make an intelligent use of his own observations. Experience in teaching engineering students has led me to endeavour, by a simple, detailed treatment, to make the work useful as a text-book on the subject.

Brief historical notes trace the evolution of the internal combustion engine from the crude gunpowder engine to modern gas and oil engines. The main features and details of the chief types of motors established in common use are shown by many illustrations, with description of the action and trials of each engine. A special chapter has been added on petroleum—oil and spirit—engines.

The account of elementary principles is intended to give exact notions of the units of measurement, and the methods

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of making accurate measurements of energy, mechanical work and power, temperature and heat. With this aim continually in view, indicators and other measuring instruments are fully described and their uses explained. I have not scrupled to work out practical numerical examples in the text, adding a few exercises. Both the British and metric systems are used throughout. An account, up to date, is given of the production, composition, combustion and heating value of petroleum, and of the different kinds of gaseous fuel utilised by the internal combustion engine. The properties of gases and petroleum vapours are dealt with as introductory to the fuller consideration of the working substance in the engine cylinder. The reader who cannot follow the more thorough mathematical treatment requisite to a complete understanding of the application of thermo-dynamics, may nevertheless avail himself in many ways of the rules arrived at. Thus, from the laws of expansion and compression, already deduced graphically from indicator diagrams, he can solve numerical problems on the work done, and heat changes in the engine cylinder during the various operations.

A chapter is given on the methods of carrying out commercial tests and scientific experiments on gas and oil engines, and on the measurements made to determine the regularity of working, the consumption of fuel per horse-power hour, and the distribution of heat energy in these engines. The more important results of experiments on combustion and explosion in the cylinder also claim a chapter.

For the method adopted in treating some parts of the subject, my thanks are due to Professor JOHN PERRY, F.R.S.

I am indebted to my colleague, Professor F. STANLEY KIPPING, F.R.S., for valuable help in kindly reading proofs of the chapters on combustion, fuels, and the working fluid ;

and I also wish to thank my former assistants, Professor ALFRED HAY, Professor W. H. EVERETT, Mr. H. R. CULLEN and Mr. J. DUNCAN, and my present assistant, Mr. A. MORLEY, who have helped in experiments on engines, gas-power installations and fuels, and in the preparation of this book.

Many engineers and engineering firms rendered valuable help in supplying tracings and cuts for illustration, and in affording me facilities for examining and testing their engines and apparatus. I have also obtained data from the records of experimental results and practical experience in the Proceedings of the Scientific Societies and Technical Journals. Reference is made, in the footnotes, to many of these sources.

WILLIAM ROBINSON.

UNIVERSITY COLLEGE, NOTTINGHAM : 1902.

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GAS AND PETROLEUM ENGINES.

CHAPTER I.

INTRODUCTORY.

A HEAT ENGINE is a machine which converts heat energy into mechanical energy. A *Gas Engine* is a heat engine in which the working fluid is a mixture of gaseous fuel and air that generates heat by its own combustion in a closed cylinder, and at the same time utilises the heat energy by expansion of the burning gases doing useful work on a movable piston.

The heat obtained by combustion of the charge of gas and air at a high temperature in the gas-engine cylinder, increases the pressure of the gases and the force exerted on the motor piston. The term **Internal Combustion Engine** *comprises both* **gas and petroleum engines**, *in which the heat is generated by* **combustion** *of the gaseous fuel with air* **inside** *the cylinder, where it is turned into work.*

The mechanical energy is directed and transmitted by the piston through the connecting rod to a crank on a steadily revolving shaft provided with a fly-wheel.

In general, a *gas-engine plant* consists of three essential parts: (1) a *gas producer* to convert solid or liquid fuel into the gaseous state—in the petroleum engine this part is called the *vaporiser* or *carburettor*; (2) the *engine cylinder* in which the heat energy is produced from the gas and utilised or converted into work done on the piston; (3) the *mechanism* to transmit the mechanical energy to the driving shaft, where it is available for the performance of useful mechanical work.

In the **Steam Engine**, the other common form of heat engine, the working substance is steam generated and heated in the boiler from an **external** source. The heat is derived from the combustion of fuel in the boiler furnace. The three essential parts of a steam engine plant are (1) the steam *boiler* with *furnace* for burning the fuel and making steam at the desired pressure—the dry saturated steam sometimes receives additional heat apart from water in a *superheater*, which is an accessory to the boiler; (2) the *engine cylinder* in which the heat is converted and utilised as work on the piston; and (3) the *mechanism* and gearing for transmission of the mechanical energy to the driving shaft.

Since the time of Watt much has been done in the development and improvement of the steam engine. In design and construction the steam engine is nearly perfect, so that we cannot expect much better economical results than its present performance. Engineers have made it a very useful servant to do all sorts of work. Stephenson caused the horses of the old stage coach to give place to the locomotive engine in the shape of his Rocket. Even at the beginning of the twentieth century, when England is covered with a network of railways, some of our readers can, doubtless from their own experience, contrast the luxuries of cheap railway travelling by express train with the laborious and tedious stage-coach locomotion. It is quite useless to dilate on the fact, that since steam has given to the master of a vessel the power of propelling his ship without a fair wind and against opposing winds, commerce and industry have been stimulated, and the natural resources of the whole world have been developed.

Still, when we bring the steam engine to account, and compare carefully its consumption of fuel with the work done by it, we find that at best it only converts about one-eighth of the total heat of the fuel into mechanical work.

The British engineer's unit of *power*, or *rate of doing work*, is one *horse-power* = 33,000 foot-pounds of work per minute, or 33,000 × 60 = 1,980,000 foot-pounds per hour.

Now, the mechanical equivalent of heat is 778 foot-lb. of work, which produces one British Thermal Unit (1 B.Th.U.), that is the heat energy required to raise the temperature of one lb. of pure water one degree Fahrenheit at 60° Fahr. The thermal equivalent of one horse-power is therefore

$$33{,}000 \div 778 = 42{\cdot}42 \text{ B.Th.U. (British Thermal Units)}$$

per minute, or $42{\cdot}42 \times 60 = 2545$ B.Th.U. per hour.

In special trial runs, a very good *steam-engine plant* working *at constant full load* of 200 horse-power and upwards, under most favourable circumstances, gives out one useful horse-power for every 2 lb. of Welsh coal burnt per hour in the boiler furnace. This consumption, equal to 1·75 lb. of good coal per hour per indicated horse-power, is regarded as an exceedingly good result seldom attained, and yet it means a utilisation of only about 9 per cent. of the total heat of combustion of the coal, 14,500 B.Th.U. per lb., measured in a bomb calorimeter.

Taking one horse-power for one hour as equivalent to 2545 British thermal units, we have, in this case

$$\frac{\text{Heat turned into useful work}}{\text{Heat energy supplied in the coal}}$$

$$= \frac{2545}{2 \times 14500} = 0{\cdot}087, \text{ or } 8{\cdot}7 \text{ per cent.}$$

We thus see that a steam-engine plant burning 3 lb. of coal per hour in the boiler furnace per useful horse-power, utilises only $\frac{2545}{3 \times 14500} = 0{\cdot}058$, or less than 6 per cent. of the heat of combustion of the coal. The other part, 94 per cent. of the total heat energy, is wasted. More extravagant results are obtained when steam engines work at less than their full or rated load.

Variation of load increases the coal consumption in large central-station steam engines for electric lighting, from 2·8 to 4 lb., and frequently 6 or 8 lb., of coal per average effective horse-power-hour.

At Birmingham, small workshop engines and boilers, tested under the unfavourable conditions of everyday working at varying loads, gave the following **coal consumption** :—

Indicated Horse-power at full load.	Observed Average Indicated Horse-Power.	Observed Coal Consumption lbs. per hour per indicated Horse-Power.
12	3	36
45	7·4	20
60	8·2	22·6
75	23·6	11·7
60	20	8·5

Here we see enormous waste of the great stores of energy accumulated for us by Nature in the coal fields. The spendthrift talks of the new fortune that will come to him, somehow, when his present fortune is spent; and people have a vague notion that some source of energy in another form than that of coal and fuel will make its appearance in the world when our present store gives out; but we must confess, with the knowledge that at least *nine-tenths of the heat energy stored up for us in Nature is now being utterly wasted* when burning coal in boilers for steam engines of small power, showing as it does that we are unworthy of the benefits vouchsafed to us, we feel that we are simply spendthrifts, placing a vague dependence on the appearance of a new fortune when our present one is dissipated. It is the duty of the engineer "to convert, adapt and apply the great sources of power in Nature for the use and convenience of Man."

In view of the large part which the steam engine has played in the industrial progress and development of the world, it is important for us to see where waste of heat occurs in converting the energy in coal into mechanical energy by means of the *steam-engine plant*, as well as for the sake of comparison with the performance of the internal combustion engine. First of all, in good types of steam boiler working at their best, at a steady rate and not forced, we have usually about 70 per cent. and seldom more than 80 per cent. of the heat energy available in the fuel utilised in generating steam. From one-fourth to one-fifth of the heat produced by combustion in the furnace is lost or carried up the chimney in the gases at the high temperature, besides the waste due to radiation, and smoke imperfectly burned. Economy is effected by using the hot furnace gases (1) to heat the feed-water, as in Green's economiser; and (2) to dry and superheat the steam. The boiler and steam pipes are clothed or "lagged" with non-conducting covering, which greatly diminishes the loss of heat by radiation from the boiler and by steam condensed. Still there is cooling and condensation of steam in contact with the conducting metal in the steam-pipes from the boiler to the engine, as well as by the cooling action of the cylinder walls.

The most common method of diminishing cylinder condensation is to use dry steam in a dry cylinder: (1) to drain all water out of the cylinder, and (2) to dry and warm the walls by live steam in the steam-jacket at a higher temperature than the mean temperature in the cylinder. Cylinder condensation is also diminished, (3) by superheating the steam, (4) by carrying out the expansion of the steam in stages in the separate cylinders of compound, triple and quadruple engines, so that the temperature drop is less in each. For maximum economy, dry steam at high temperature and pressure is obtained (1) by the use of water-tube boilers in which the solid-drawn tubes of steel withstand high pressure and give large effective heating surface with good circulation; and (2) superheating to dry the steam and keep it hot enough to prevent condensation in the engine cylinder.

The largest and best steam engines in trial runs require at least 250 to 400 B.Th.U. per minute per horse-power indicated in the cylinder. Thus the *thermal efficiency* of the engine, namely *the ratio of the heat turned into work done on the piston to the heat supplied in the steam*, varies from $42 \cdot 42 \div 400 = 0 \cdot 10$, or 10 per cent., to about 17 per cent. in compound condensing engines of 50 to 1000 horse-power when using highly superheated steam. It is obvious that by far the greatest loss, 83 to 90 per cent. of the available heat in the steam, takes place here in the engine, owing to temperature conditions and the law of conversion of heat into work. Besides this inevitable loss, there is waste of heat depending on the design and construction of the particular engine. The efficiency of the engine multiplied by that of the boiler and furnace gives their combined efficiency.

Lastly, at least one-tenth to one-fifth or more of the work done on the piston is lost or absorbed in friction of the engine mechanism at full load and with good lubrication. So that the actual work available at the driving shaft is at most four-fifths to nine-tenths of the indicated work. The efficiency of the mechanism or **mechanical efficiency** is then 80 to 90 per cent. The highest value of the efficiency of the whole steam plant, furnace and boiler, engine and mechanism at full load is about $0·8 \times 0·17 \times 0·9 = 0·12$, or 12 per cent., and a good average result would be $0·7 \times 0·10 \times 0·8 = 0·56$, or 5·6 per cent.

This efficiency is the fraction of the heat of combustion of the coal that is converted into actual work available for useful purposes at the driving shaft of the engine. Engineers often state the performance of the plant by the number of pounds of coal consumed per hour per useful horse-power. For accuracy, the heating value of the coal must always be given as determined by direct measurement in the bomb calorimeter.

At present the steam engine is very nearly as economical as it can be made for the limits of temperature at which it receives and rejects the steam. Its possibilities are governed by the **law for the conversion of heat into work**, namely, that the temperature or intensity of heat energy in the steam renders the heat *available* for the performance of mechanical work. The greater the range or difference of temperature of the working fluid in the engine cylinder the larger the proportion of heat energy utilised or turned into work. The **ideal** *perfect heat engine can only convert into work the fraction* $\frac{T - T_1}{T}$ *of the whole heat* H *supplied in the working fluid at the absolute temperature* T, *where* T_1 *is the lowest temperature of the stuff leaving the engine.* The remaining part $\frac{T_1}{T}$ of the heat H is unavoidably lost. In other words, the thermal efficiency is proportional to the range of temperature worked through by the ideal heat engine divided by the absolute temperature of the heat supply.

Clearly, from this point of view, the greatest heat economy is obtained (1) by working at the highest possible initial temperature, and (2) by great range of expansion.

But serious practical difficulties are met with in the use of steam as the working fluid at high temperatures, because the pressure of steam rises so very rapidly that greatly increased strength is necessary in the boiler and steam pipes, with increased first cost and maintenance. On the other hand, the highest practicable steam pressure gives the advantage of maximum power per unit weight of engine, an important consideration in marine engines. Large development of power from a small weight of engine is also secured, without loss of efficiency, by increase of piston speed. For a given type of engine there is a certain ratio of expansion which gives the minimum weight of steam engine and boiler per horse-power.

Already the comparatively small **gas engine** has achieved promising results. In towns where *coal gas* or lighting gas is distributed by gas mains, motive power is readily generated by the gas engine, which is compact, handy and occupies small space. Besides the gas supply and exhaust pipes, all that is required is a cooling tank for the circulating water which keeps the cylinder cool for lubrication. A great convenience of the gas engine is that it can be started in a few minutes. The gas is lighted to heat the *ignition tube* up to bright redness while the engine is being oiled. For electric ignition the current is obtained and the sparks produced previous to starting. The engine is started by turning on the gas, and giving the fly-wheel a few turns to draw the explosive mixture of gas and air into the cylinder and compress the charge until ignition takes place and fires the charge at the proper point of the stroke, driving the piston with sufficient force to keep the engine going. During starting, the compression is eased by a cam which holds the exhaust valve partly open.

Large engines are provided with **self-starters.** Usually *compressed air* is stored in a steel reservoir and is admitted into the cylinder through a starting valve. The engine is driven by compressed air until speed is got up to draw in, compress and fire a regular charge. Another common method of starting is as follows: turn the fly-wheel to bring the piston into the position to commence the working stroke, with the crank over the dead point. Introduce into the combustion chamber, by means of a force pump, a charge of gas and air in proper proportions for explosion. When the piston begins to move, open the *timing valve* to allow communication between the compressed charge and the red-hot ignition tube which fires the charge, and thus gives an impulse to the piston sufficient to drive the mechanism.

To stop the engine, simply turn off the supply of gas. The gas engine is thus especially adapted for intermittent work. When kept properly cleaned and lubricated, the gas engine requires little or no attendance. It has come extensively into use, and has found numerous applications for various industrial purposes.

In the United States rich *natural gas*, obtained in great quantities from wells, is conveyed in pipes economically over long distances, distributed for supply at industrial centres, and used in modern gas engines of sizes up to 650 and 1500 brake horse-power for electric light and power purposes.

Gas Producer.—In this country the high price of lighting gas makes the *unit of heat* from it more expensive than that by burning the parent coal directly; hence for large powers a **cheap fuel-gas** made from *anthracite coal* and especially adapted for gas engines was introduced by Mr. J. Emerson Dowson. Dowson gas has been extensively used for driving gas engines, and the economical results obtained with this *gas-engine plant* are interesting and important, the *gas producer* and *gas engine* corresponding to the steam boiler and steam engine.

Many careful tests and records of ordinary working show that the Dowson gas-producer plant, with different types of gas engine, is able to run continuously night and day at full load on one pound of anthracite coal per hour per brake horse-power. We have seen that a first-class steam engine and boiler can only give one useful horse-power for every two pounds of good coal burned per hour, that is, twice the amount of fuel required by the gas-engine plant under similar conditions.

In the case of a gas engine developing 150 indicated horse-power with **Mond gas**, at Winnington, the fuel consumption at full load was 0·92 lb. of **common bituminous slack** per indicated horse-power-hour. The calorific value of the common Nottingham slack used was 11,520 B.Th.U. (British thermal units) per lb. The combined thermal efficiency of the Mond gas producer and gas engine is practically 25 per cent., and taking the mechanical efficiency of the engine as 85 per cent., the combined efficiency of the whole plant comes to $25\,\% \times 85\,\% = 21{\cdot}25\,\%$. In other words, 21 per cent. of the heat energy in the cheap common slack fed into the Mond gas producer is converted into useful work. Throughout the year 1898 the same gas engine, coupled direct to a dynamo, ran 95·4 per cent. of the total 8760 hours in the twelve months, at the average of 115·8 indicated horse-power, and the average fuel consumption was 1·03 lb. of the free burning coal fed into the Mond gas producer per hour per indicated horse-power, or 1·76 lb. of slack per electrical unit (1000 watt-hours) generated by the dynamo and measured at the switch-board. Gas engines of 650 horse-power are now working with Mond gas made from common slack or small bituminous coal. A novel feature in the small Mond gas plant, without ammonia recovery, is that part of the exhaust from the engine is blown into the producer with air and

of combustion in the cylinder, even small gas and petroleum engines actually convert into useful work from 20 to 30 per cent. of the heat of combustion of the charge, and are thus less wasteful of fuel than the largest and most carefully constructed steam-engine plant. Instead of the steam boiler we have the **Gas Producer** to make the working substance, cheap fuel gas, from coal, and its thermal efficiency is 70 to 80 per cent. The mechanical efficiency of the gas engine at full load is 80 to 90 per cent. The combined efficiency of the whole plant, gas producer, engine and mechanism, at full load, is about 80% × 35% × 90% = 25%, and a good average value is 70% × 25% × 85% = 15%.

The stand-by loss of fuel burned in the gas producer when idle over night is much less than in the steam boiler, which takes 10 per cent. of the whole fuel consumption to keep it standing without making steam, with the stop-valves closed and the fires banked. The quality of both the steam and gas is reduced, as well as the efficiency of the producers when these are forced to work too rapidly. In the boiler or steam-producer the bubbles of steam carry off some water spray, which collects into drops of water in the steam, called "priming," and greatly increases the tendency to condensation. Moreover, forcing the fires tends to incomplete combustion, even with careful stoking. In the generator or gas-producer, when the incandescent fuel is not deep enough, and the steam blast is increased too much, some of the steam and air may be forced through channels or holes in the fuel and escape decomposition, making bad gas.

The most recent application of the gas engine is in the utilisation of the waste gas from the blast-furnace for motive power in the engine cylinder. The gas from coal-fed blast furnaces consists of about 30 to 35 per cent. by volume of combustibles, and the calorific value is from 100 to 120 B.Th.U. per cubic foot, at 60° F. and atmospheric pressure. The poorest gas, from the common coke-fed blast furnace, has only 20 to 35 per cent. by volume of combustibles, and its heating value varies from about 75 to 120 B.Th.U. per cubic foot. The blast-furnace gas when cooled is mixed with air and highly compressed, to about 150 lb. per square inch, in the engine cylinder to make it ignite more readily in presence of such a large proportion of non-combustible constituents.

A Simplex single-cylinder engine of 200 horse-power was started at Seraing, Belgium, in April 1898, with blast-furnace gas. Since the year 1899 other large gas engines, of 600 and 1000 horse-power, have been working with blast-furnace gas. Gas engines of two or more cylinders are now made in sizes up to 1500 and 2500 horse-power.

Independent of coal altogether, we have modern representatives of the steam boiler in the numerous modern PRODUCERS OF GAS from cheap gas-oils and intermediate shale-oils. As an example, we select the MANSFIELD OIL-GAS APPARATUS, which needs no skilled labour, and produces gas from oil of any kind—mineral, vegetable, or animal; *native* oils, as crude and partially refined petroleum in the United States of America, Russia, Burmah and India; *cocoa-nut* and *palm oils* in Africa and South Seas: *castor-oil* in East Indies; *linseed-oil* in Brazil; and *olive-oil* in Italy; mutton *fat* and *grease* in Australia and South America; various kinds of animal oils or fatty refuse in Jerusalem; and intermediate shale-oils in Scotland. Attached to the producer is the simplest kind of gas holder, which stores the gas for use in the engine. This arrangement may be used in the most remote country districts all over the civilised world, being equally available to the American backwoodsman and the Australian squatter.

In the **Petroleum Engine** the heat generated by the combustion of oil vapour in the cylinder is used directly to expand the products of combustion and drive the piston. Advantage is taken of the high efficiency of the internal combustion engine to convert into work the heat from petroleum without the gas-producer plant. The drawback in this case is that the *unit of heat* obtained by burning refined petroleum oil costs eight times that from coal. Coal at 15*s.* per ton costs $\frac{1}{12}$*d.* per lb., which gives 14,000 B.Th.U. Petroleum at 8*d.* a gallon costs 1*d.* per lb. of total heating value, 21,000 B.Th.U. Hence, one British thermal unit from petroleum at 1*d.* a gallon would cost the same as from coal at 15*s.* a ton. Common refined petroleum oil, that is ordinary burning lamp oil or paraffin oil, which may be procured in abundance

almost anywhere, and used in the oil engine at once as fu
and working substance, becomes a safe and economical sourc
of power. The wholesale prices of these oils, delivered nake
in London or Liverpool, after allowing 1*d.* per gallon for th
barrels, vary with demand and supply in the market; Russia
ordinary (Russolene) and American "Royal Daylight," 4*d.* pe
gallon; Scotch gas-oils, and intermediate oils, 3*d.* per gallon
For inland towns the cost of carriage must be added. Still
these prices do not prohibit the economical use of oils in prime
motors, although the cost of coal is very much less in the United Kingdom. In many countries crude petroleum or other suitable oil costs less than coal. The consumption of oil in the petroleum engine is less than a pint per hour per brake horse-power. Taking petroleum at 4*d.* per gallon, the cost of oil per hour is less than one half-penny per hour per effective horse-power.

The **Petroleum Oil Engine** is completely self-contained, and employs common petroleum oils directly, the oil *vaporiser* forming part of the engine. As regards supply of the working substance, we have here entirely different conditions of working to those in steam and gas engines. The steam boiler is relied upon to supply dry steam to the steam engine at the desired pressure. For a gas engine the supply of gas is turned on at the gas-cock, and, apart from the engine, the gas is distilled in a retort, or produced in a generator, washed, purified and prepared by means of the gas plant, to give satisfactory results in the motor cylinder, whether used for a long or short period. Whereas in the oil engine the oil for each charge is taken by the engine from the oil tank, converted into vapour by heat in the vaporiser, and mixed with the air for combustion in the engine cylinder, where the charge is compressed and fired as in the gas engine.

The performance of the oil engine depends greatly on (1) the kind of oil used; (2) how it is treated in preparing the charge, including the temperature of the vaporiser; and (3) automatic control of the oil supply by the governor to regulate the speed.

The **Petroleum Spirit Engine** has a *carburettor* or vaporiser in which "petrol" or light *petroleum spirit* is vaporised and mixed with air in suitable proportions automatically by the engine, to adapt the charge to the varying conditions of load. The carburettor is that part of the plant in which the air is charged with a suitable proportion of hydrocarbon vapour before entering the cylinder. This form of petroleum motor or internal combustion engine is well suited to drive autocars or light motor vehicles, and when started it is found to work with economy for long distances without attention. In a 1000 mile trial by the Automobile Club, extending over three weeks in wet and dry weather, on all conditions of roads and some of the steepest road gradients in England and Scotland, the vehicles driven by petroleum spirit in the internal combustion engine proved the most successful. In various other trials the cost of petroleum spirit consumed, at 1*s.* per gallon, was from ½*d.* to 1½*d.* per ton per mile; and the total cost was about 2½*d.* per ton-mile for a motor carriage with pneumatic tyres. The objections to these motors for vehicles are: (1) the smell and danger from the use of highly inflammable petroleum spirit; (2) the vibration owing to the explosions in the cylinder, and the noise of the gearing for change of speed; (3) the great prime cost of pleasure vehicles, also the trouble and expense of renewal of rubber tyres, owing to rapid wear on country roads.

Internal Combustion Engine.—In studying the construction of a machine like the internal combustion engine, the student would do well to examine a good modern engine, make drawings of its several parts, and carefully observe its action for himself. The information gained in this way will amply repay him for the time and care expended.

There are many forms of the internal combustion engine. The construction and essential parts of the best modern engines are shown in Chapters IX. and X. These are all modifications of one type of engine working on the FOUR-STROKE CYCLE, invented by BEAU DE ROCHAS in 1862, and carried out successfully in the Otto "Silent" gas engine of 1876. After years of experience, by a process of the survival of the fittest, the *four-stroke cycle of Beau de Rochas* has proved best suited for ordinary work, and its chief features are n generally adopted by leading makers of gas and petroleu engines as the simplest lines on which an internal combusti engine can be constructed to give the most satisfactory resul

The **simplest and most common form** *of internal com bustion* engine has a single-acting **cylinder**, open to the air the front end next the crank, and closed by a **trunk pisto** directly joined to the crank by a connecting rod. The pisto is usually made as light as possible, in length about twice th diameter of the cylinder, for which it is an easy fit when col Leakage past the piston is prevented by four or more spli rings of cast iron, sprung into grooves in the piston, and mad to press uniformly all round against the cylinder. Th cylinder is fitted with a **liner**, made of special hard cast-iron in which the piston works. This liner is free to expand o contract, and can be easily replaced when worn. It must b bored exactly circular in section and truly in line when secured to the cylinder. The space between the liner and outer casting of the cylinder forms part of the **water-jacket,** which extends to the back end of the cylinder and around the valves. The back cover, with combustion chamber and valves, is bolted on the back end of the cylinder and keeps the liner in position.

The cylinder is longer than the piston stroke, leaving a clearance space at the back end, called the **combustion chamber** or cartridge, into which the explosive mixture is compressed. The ratio of the clearance or compression volume to the total volume of the cylinder determines the amount of compression, and is called the **ratio of expansion,** In modern engines this ratio is about one-fifth, that is the clearance or compression volume is 20 per cent. of the whole volume of the cylinder occupied by the charge before compression and after expansion. In this way a mixture of gas and air drawn into the cylinder occupies 5 cubic feet at atmospheric pressure, is rammed back into the clearance space and compressed by the piston until it occupies only one cubic foot before ignition, and during combustion the gases expand to 5 cubic feet, driving the piston outward.

The BEAU DE ROCHAS CYCLE consists of four operations, which take place in the working cylinder on one side of the piston, during four consecutive strokes, giving in a single-cylinder engine at full load one explosion or working stroke for every two revolutions of the crank-shaft.

1. **Charging or Suction.**—During the first forward or *out*-stroke of the piston, a mixture of gas and air is admitted to the cylinder by separate *lift-valves*, of mushroom type, held on their conical seatings by spiral springs, and opened by levers worked from cams on the side-shaft, which is driven at half the speed of the crank-shaft.

2. **Compression.**—During the return or *in*stroke all the valves are closed, and the mixture of gas and air is compressed by the piston into the clearance space.

3. **Explosion and Expansion.**—The compressed charge is *ignited* by an *incandescent tube or electric spark* just as the crank passes the dead point, and the pressure, due to the heat energy developed by the combustion, rises so rapidly that the maximum pressure is reached before the piston has moved appreciably on its second forward or *out*stroke. This is the only **working stroke**, and the piston is pushed forward with great force by the pressure of the burning and expanding gases. The pressure or force on the piston is transmitted through the connecting rod to the crank-shaft.

4. **Exhaust.**—When the piston has travelled about four-fifths of its working stroke, the exhaust valve is opened to give "release," and reduce the back pressure. Exhaust takes place during the second return or *in*stroke when the products of combustion are discharged from the cylinder, with the exception of what remains in the clearance space untraversed by the piston. These burnt gases mix with the incoming gas and air of the next fresh charge.

In some modern gas engines, SCAVENGING AIR under slight pressure is admitted to the cylinder towards the end of the exhaust stroke, to sweep out the burnt gases from the clearance space through the exhaust pipe, and so thoroughly cleanse and cool the passages and exhaust valve, leaving the clearance space full of pure air. Scavenging is specially desirable with gas of low heating value, such as poor fuel gas and blast-furnace gas containing small proportions of combustibles, which require to be well mixed with the air for combustion, and this is retarded by the inert gases present.

An essential feature of the internal combustion engine is the **water-jacket**, through which water is kept constantly circulating to *cool the cylinder walls* that are exposed to the high temperature of the burning gases inside the cylinder. Regulation of the cylinder temperature is necessary for proper **lubrication** of the internal surface of the cylinder swept by the piston, and to prevent over-heating of the exhaust valve and passages causing trouble by premature ignition of the charge, which seriously interferes with the working of the engine.

For extremely small engines the cylinder can be kept cool enough (about 400° Fahr.) for lubrication, by radiating plates and ribs cast on the cylinder exposing a large cooling surface to the air. Even with a two-cylinder petroleum spirit engine of 7 horse-power for a motor-car, an air fan has been used to blow a steady current of cold air upon the flanged or ribbed cylinders, in order to do without a water-jacket and avoid the trouble of water cooling. In autocars or light vehicles driven by petroleum motors, the consumption of cooling water to be carried is reduced (1) by the use of water coolers or radiators, consisting of cooling pipes through which the water is circulated by a pump; and (2) by means of a fan or vanes on the fly-wheel circulating cold air around the water-cooling pipes, arranged to expose as large a surface as possible.

In stationary engines the water flows by gravity from *cooling tanks*, at a higher level to give head of water, through the inlet pipe, provided with a stopcock, enters below and circulates around the cylinder, leaving at the top of the cylinder and back again to the top of the tank by the outlet pipe sloping upwards from the cylinder so as to avoid syphoning, and to keep the water-jacket surrounding the cylinder always full of water when the engine is working. The *temperature* of the water gradually rises until a steady state is reached at 140° to 200° Fahr., when the engine works much better than with cold water taken from the street mains, because a more uniform temperature is maintained in the cylinder walls. In time of frost the jacket should be drained empty, when the engine is not working, to prevent fracture of the cylinder or combustion chamber by the water freezing. In large engines of 50 horse-power and upwards, it is generally necessary to provide circulation of cooling water, not only around the cylinder, valve box, and valve spindles, but also in the interior of the motor piston and of the conical seated lift-valves, made of large masses of metal forming part of the inner surface of the cylinder exposed to the flame and raised to incandescence by the combustion of the gases.

The cooling water-jacket absorbs and carries away from one-quarter to one-half of the total heat generated. Moreover, the cooling action of the water-jacket through the cylinder walls also tends to prevent the development of the maximum temperature and pressure from the combustion of the charge inside the cylinder. Some means may be devised by which the heat lost in the jacket can be utilised, or at least greatly reduced. *The first rule in gas-engine design is to reduce to a minimum the area of all cooling surfaces in contact with the hot gases.* The loss of heat by the gases diminishes rapidly in proportion as the diameter of the cylinder increases, and a single cylinder of largest diameter will utilise most of the heat. It is obvious that for the combustion chamber and clearance space, the ratio of surface to volume should be a minimum, that is, these spaces should be made as nearly spherical in shape as possible. The surface increases as the square, and the volume as the cube of the cylinder dimensions, so that the ratio of the cooling surface in contact with the gases to the volume occupied by them becomes less the larger the engine. This is one reason why the *rate of consumption of gas per horse-power is less in* **large engines** *than in small ones.* The loss due to friction of mechanism is also less in proportion for large engines. Again, the more quickly the piston moves under the action of the hot gases the less *time* is allowed for loss of heat to the cylinder walls. High piston speed is also favourable to rapid combustion of the highly compressed charge. However, the mechanical strength of the mechanism limits the average piston speed to from 450 to 700 feet per minute. Very high speed or compression reduces the durability of the engine by extra wear and tear.

By **compression** of the charge of gas and air before ignition (1) more power is obtained from a given size of cylinder, and (2) poor quality of gas can be used, giving (3) more certain ignition and rapid combustion, with (4) higher thermal efficiency. Experience abundantly proves that *increase in compression of the charge means greater economy of gas per hour per horse-power.*

Compression is increased by diminishing the clearance volume occupied by the residual gases after exhaust, and into which the charge is compressed. Some of the **advantages of high compression** and small clearance are obvious.

The smaller the volume of the clearance, the less the quantity of burnt gases left in it to mix with the next charge, and the less the area of cooling surface of cylinder walls in contact with the more highly compressed charge at explosion.

A weak mixture of poor gas with the air necessary for combustion, which will not burn at the ordinary pressure and temperature, may be made combustible by high and rapid compression also raising the temperature. In the engine cylinder, cheap fuel gas, containing a small proportion of combustibles mixed with inert gas, mainly nitrogen, has the latter increased by the nitrogen in the air which is added to furnish the oxygen for combustion, and the mixture is still further diluted by the burnt products left in the clearance space of a non-scavenging engine. Therefore, the gas and air must be thoroughly mixed and highly compressed to bring the particles of combustible gas and oxygen close together, and at the same time raise their temperature so as to ensure, with the electric spark or incandescent tube, that certainty of ignition and rapidity of combustion essential for satisfactory results. In present practice, when using Dowson gas and Mond gas, the charge is compressed to upwards of 100 lb. per square inch before ignition, and with poor blast furnace gas from 100 to 150 lb. per square inch, ing a low mean pressure during explosion stroke when compared with rich coal gas, because of their relative heating values. With low compression the weak mixture of poor gas is difficult to ignite, and, if it burns at all, the rate of propagation of the flame is at first slow compared with the high speed of the piston. Consequently, the hot gases are exposed to the cooling action of a large surface of the cylinder walls, and great loss of heat takes place to the water-jacket at the highest temperature during the stroke, whilst combustion is still going on until the gases are discharged into the exhaust pipe. Moreover, other troubles are brought about by the slow and retarded combustion of the weak charge, instead of burning quickly and completely. When the exhaust valve closes, any smouldering gas left in the compression space is apt to ignite the fresh incoming gas, which soon forms an explosive mixture, causing (1) "back-firing," and explosions in the air pipe, or else (2) "pre-ignition," the name given to premature ignition and combustion of the charge during the compression stroke.

Pre-ignition may also be produced by the additional heat from too high compression of the charge, and by *over-heating* of the inner surfaces of the cylinder, especially the exhaust valve and piston which ignite the gas and air under compression before the piston gets to the end of its compression stroke, producing sudden rise of back-pressure. Advantage is taken of this tendency, and by careful regulation of the temperature in the compression space, **regular and automatic ignition** of the charge is obtained in the Hornsby-Akroyd and other petroleum engines, in which the hot vaporiser forms part of the compression space.

Unburnt and incompletely burnt gases, discharged into the exhaust, are likely to be fired by the exhaust products from the following charges, producing explosions in the exhaust pipe. All these irregular explosions are highly objectionable, give sudden shocks to the mechanism of the engine, and seriously interfere with the regularity of running.

Again, for a given size of cylinder, higher compression of the charge before ignition forces a greater weight of gas into the clearance volume, and the ratio of the cooling surface of enclosing walls per unit weight of gas is smaller at the highest temperature of explosion. Then the highly compressed charge ignites promptly and burns rapidly, developing a greater amount of heat per unit volume, and this heat is more quickly converted into work done on the piston by the great force from the rapid combustion. Hence, for a given quantity of gas consumed, the mean pressure during the working stroke is increased. The explosion pressure rises more quickly to its maximum value, and a shorter interval of time is allowed for loss of heat to take place by cooling. The maximum pressure reached early in the explosion stroke also allows *greater range of expansion of the products of combustion after the heat is generated*, and consequently a greater range of temperature in the engine cylinder, which greatly increases the thermal efficiency.

A perfect gas engine working on the Beau de Rochas cycle under ideal conditions, with no water-jacket loss, and all the heat developed instantaneously at constant volume, could only convert into work done on the piston the fraction of heat supplied by explosion, indicated by the

$$\text{ideal thermal efficiency} = 1 - \left(\frac{1}{r}\right)^{\gamma-1};$$

where $\frac{1}{r} = \frac{\text{compression volume}}{\text{total volume of cylinder}}$, called the *ratio of expansion*, and γ = the ratio of the specific heats of the gas. Suppose $\gamma = 1{\cdot}37$ for coal gas, the greatest possible efficiency of an ideal perfect gas engine working on the Beau de Rochas cycle and having $r = 5$, would be 45 per cent.; and $r = 7$ would give 55 per cent. efficiency. In a careful test of a small gas engine (page 254) with $r = 5$, the Author has observed that 28·7 per cent. of the heat supplied by the coal gas was converted into actual work done on the piston. A "Premier" engine of 500 actual horse-power, with Mond gas has a thermal efficiency of 33·7 per cent. (see page 585.)

Regulation of Speed.—The speed of an engine is usually regulated by a **governor** and a **fly-wheel**. The function of the governor is to regulate the number of revolutions or cycles that the engine makes per minute, by regulating the mean pressure acting on the piston in proportion to the load or resistance to be overcome. The fly-wheel reduces any sudden changes in the speed of rotation during a single cycle of operations.

The fluctuation in speed is due to (1) the variation of the pressure on the piston in the cylinder, modified by (2) the inertia of the reciprocating parts of the engine, and (3) the angularity of the mechanical combination of crank and connecting rod, which result in a variable turning effort on the crank-shaft as compared with the load or resistance to be overcome by the engine.

The action of the common form of centrifugal governor depends on the change of centrifugal force of the rotating pendulum balls produced by the change in speed. When the speed of an engine increases beyond a certain limit, the increased centrifugal force makes the governor balls fly out and lift the sleeve sliding on the spindle, and by means of levers operates the admission valve to reduce or entirely cut off the charge until the speed falls to the normal.

A rotating body of weight W lb., making n revolutions per minute, about an axis at a radius of r feet, and at a velocity of $v = 2\pi r . \frac{n}{60}$ feet per second, is acted upon by a centrifugal force,

$$F = \frac{W v^2}{g r} = \frac{W \pi^2 r n^2}{900 g} = \frac{W r n^2}{2937}.$$

This expression becomes

Centrifugal force $= 0 \cdot 00034\, W r n^2$ lb.

The centrifugal force increases as the square of the number of revolutions per minute, and in a loaded governor has to lift not only the governor balls and the centre weight on the sleeve, but also to overcome the resistance of the spiral spring on the governor, which can be adjusted for different speeds by the initial compression of the spring. In some governors the action depends on the inertia of an *oscillating* body like a pendulum or weighted arm with screw adjustment. There are many other forms, as vibrating and air pump governors.

The following are the usual **methods of governing** the modern internal combustion engine :

1. In the "*hit-and-miss*" plan, most in use, the governor opens the gas-admission valve to admit a full charge of gas at normal speed, and acts on the gas-valve levers to cut off the supply of gas completely for one or more cycles when the speed is too high. Only air then enters the cylinder, is compressed, expands and is discharged, cooling the cylinder and passages, as well as sweeping the burnt gases out of the clearance space. After a miss or cut-out the cylinder is cooled, so that the next charge contains more gas and air than usual, and gives an abnormally violent explosion, exerting greater force on the piston. This irregularity is modified and the regulation of the speed maintained by the use of heavy fly-wheels on the crank shaft, which, however, means extra loss by journal friction. As regards economy of gas the great advantage of this method of working is that the mixture of gas and air can always be kept in the best proportions, and under the same compression for prompt ignition and perfect combustion.

2. Before making a complete cut-out it is usual to *vary the proportion of gas and air* in the charge, by the governor *throttling the gas supply*, regulating the opening of the gas inlet valve, with full air supply, so that the strength of the explosive mixture is diminished to suit the load and an impulse is obtained every cycle. This can only be done within narrow limits, because the weak charges burn slowly and imperfectly, and become difficult to ignite.

3. Another mode of governing is by *throttling or reducing the quantity of the charge* of explosive mixture taken into the cylinder, without altering the proportions of gas and air. There is an explosion every cycle, tending to regularity of turning effort, whilst the amount of the charge, and consequently the force of each impulse, is graduated according to the load on the engine. If the full load is suddenly thrown off, there is one heavy charge already in the engine, although the governor acts instantly, and there may be another under way partially reduced by the action of the governor. The tendency to speed up the engine is reduced by suitable fly-wheels. This mode of regulation of speed has proved effective

for engines having two or three cylinders working with rich natural gas in the United States. The drawback is that when governing at a high speed by throttling the charge, the varying quantity of gas drawn into the cylinder mixes with a definite volume of the products of combustion left in the clearance space and makes the compression low and combustion slow. With poor fuel gas, difficult to ignite at best under high compression, the combustion is likely to be retarded and rendered uncertain by the larger proportion of inert gases at reduced pressure. Throttling also increases the back-pressure.

The above methods may also be applied to the petroleum engine, in which the speed is usually regulated by the governor *throttling the oil-inlet valve*, also

4. By *holding* the *exhaust valve open*, then the inlet valve remains closed and prevents a fresh charge being drawn into the cylinder, since no vacuum is formed by the charging stroke of the piston.

5. With electric ignition the point of contact may be varied automatically by the centrifugal governor, to *retard the time of ignition*, and the combustion of the charge can be made to take place at any point of the working stroke and so regulate the speed of the engine.

We have seen that, in the Beau de Rochas cycle, an impulse is given to the piston only once every four strokes or two revolutions of the crank-shaft, and this irregularity in the driving force is increased by the action of the governor cutting out one or more charges on account of a change in speed. Large engines have two or three single-acting cylinders arranged to work on one crank-shaft and an explosion occurs once every revolution, or once every two-thirds of a revolution at regular intervals, which tends to reduce the variation of the turning effort.

The function of the **fly-wheel** is to reduce the fluctuation of speed of the crank-shaft, due to the variation of the turning effort as compared with the mean resistance at each instant throughout a cycle of operations, by storing up energy during the explosion stroke, and giving it back to the shaft to keep up the speed during the other three strokes. In a single-cylinder engine, the work done by the gas on the piston during an explosion stroke has to drive the whole mechanism, and overcome the load through the four strokes in the cycle. Clearly the fluctuation of speed will be greatest during an explosion.

On the indicator diagram, Fig. 1, heights represent pressure of gas on the piston, horizontal distances the length of stroke, and the area H E F G enclosed by the curves shows the effective work done on the piston per square inch of its area in one complete cycle of operations. Plotting the pressures throughout the four strokes on a base line A D from ignition of charge at E to the end of compression of the next charge gives the thick line E F G H K M L. The area A E F G H represents the gross work done by the gas on the piston during the explosion stroke. Deducting the work spent by the piston on the gas in the compression stroke, that is the area K D L M equal to H E A, gives the effective work done on the piston during a cycle, if we neglect the work spent in pumping during the suction and exhaust strokes. In case the resistance overcome in each stroke is constant, the area A B C D of work against resistance in four strokes is equal to area A B E F G H minus the compression area K M L D or H E A, that is the effective work. Then the excess energy received by the piston and stored up in the fly-wheel during

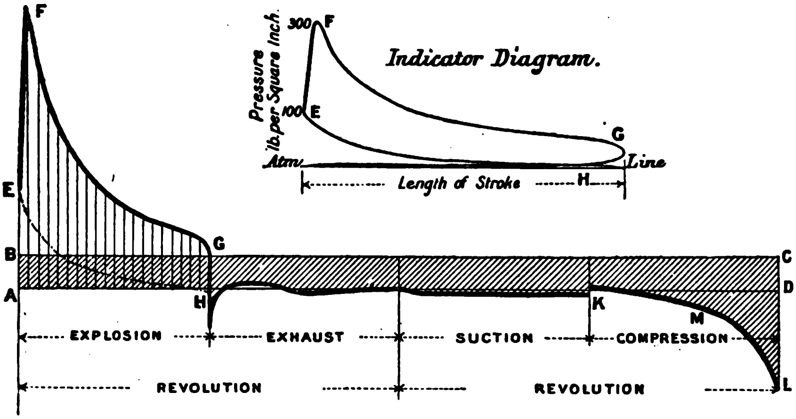


FIG. 1.—GAS ENGINE INDICATOR DIAGRAM.

the explosion, above the work performed in overcoming resistance during that stroke, is equal to the work done in the other three strokes, including the work of compression. For a rough approximation we may assume that the excess energy, to be stored up by the fly-wheel without increasing its speed beyond the prescribed limit during the explosion stroke, is equal to three times the mean work required per stroke.

If W = the weight of the heavy rim of a fly-wheel, neglecting as usual the comparatively small weight of the arms and boss ; r = the radius of gyration, taken as the average effective radius of the rim in feet ; when the wheel makes n revolutions per minute the speed of the rim at radius r feet is $v = 2\pi r.\frac{n}{60}$ feet per second, and the **energy of the fly-wheel** is

$$E = \frac{W v^2}{2g} = 0{\cdot}00017\ W r^2 n^2 \text{ foot-lb.}$$

The fluctuation or excess energy, e, which the fly-wheel has to store up and supply again as work, between the limits of speed n_1 and n_2 revolutions per minute, is equal to the difference in the total stores of energy in the fly-wheel when running at these extreme speeds, namely

$$e = \frac{W}{2g}(v_1^2 - v_2^2) = 0{\cdot}00017\ W r^2 (n_1^2 - n_2^2).$$

Let the mean speed be $n = \frac{1}{2}(n_1 + n_2)$,
it is easy to show that,

$$e = E \times 2\left(\frac{n_1 - n_2}{n}\right) = E \times 2q = \frac{W v^2}{g} \times q,$$

where q is $\frac{n_1 - n_2}{n}$, the ratio of the greatest range of speed to the mean speed, and 100 q is the percentage *fluctuation of speed or unsteadiness.* From this expression we can calculate the energy E of the fly-wheel, or the weight W of the rim, required to keep the variation of speed within the range n_1 to n_2 revolutions per minute during the explosion stroke, when the excess work e is being stored up in the wheel.

Now if we assume as above, that in the single-cylinder four-stroke cycle engine, the excess energy e, stored up during the explosion stroke, is equal to three times the mean work done per stroke, we have

$$\text{work performed per stroke} = \frac{e}{3}, \text{ and } E = \frac{e}{2q};$$

therefore, the number of strokes to give energy E is

$$\frac{e}{2q} \div \frac{e}{3} = \frac{3}{2q}.$$

In other words, for the extreme range of speed, n_1 to n_2 during a cycle, the energy E of the fly-wheel at the mean speed n must be equal to the work done in $\frac{3}{2q}$ strokes.

The fluctuation q varies from $\frac{1}{100}$ for electric lighting engines to $\frac{1}{20}$ for ordinary machinery.

For instance, if the mean speed for a single-cylinder gas engine is 200 revolutions per minute, and the extreme variation of speed allowable is 1 per cent., namely, between 201 and 199 revolutions per minute, the energy of the fly-wheel at 200 revolutions per minute must be equal to 50 times the fluctuation of energy which the wheel has to store up and give out again to the crank-shaft within this range of speed; or approximately equal to the work done during 150 strokes, of which one in every four is an explosion stroke. The energy of the fly-wheel at the mean speed is equal to the work done in $\frac{150}{4} = 37{\cdot}5$ explosion strokes. Fly-wheels are usually designed to have the energy of 35 to 40 explosion strokes at the mean speed for single-cylinder, and of 30 impulses for two-cylinder electric lighting engines in which the fluctuation of speed during any one revolution should not exceed 1 per cent. at steady load, inasmuch as the light emitted by a glow lamp varies about 7 per cent. for each 1 per cent. change in the electric pressure, and this is proportional to the speed.

When governing, an explosion is missed occasionally, and in that case the fly-wheel has to supply energy to drive the mechanism through seven strokes which will rather more than double the variation of speed. The extreme range of speed from full load to running light should be controlled by the governor and not by the fly-wheel.

Although an engine runs at a regular speed of the same number of revolutions per minute, yet the fluctuation of velocity during each revolution may be considerable. The velocity curves, Fig. 2, were obtained from records traced by Ransom's cyclometer. The steam engine tested was a good tandem compound engine indicating about 15 horse-power. The Atkinson gas engine is also a steady running motor. The steam engine piston receives two impulses, and the Atkinson gas engine one impulse per revolution.

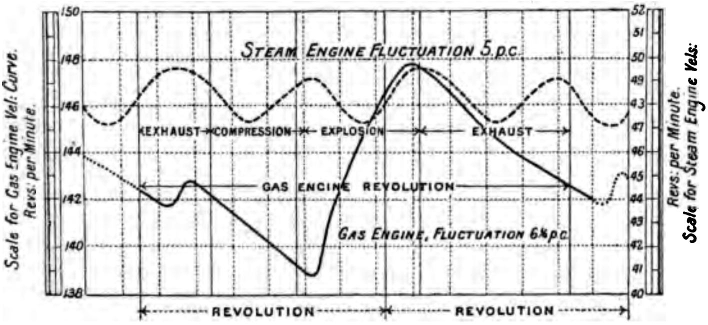
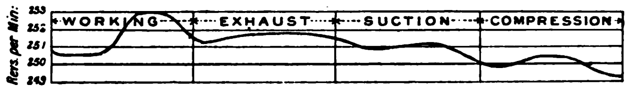


FIG. 2.—CYCLICAL VARIATION OF SPEED.

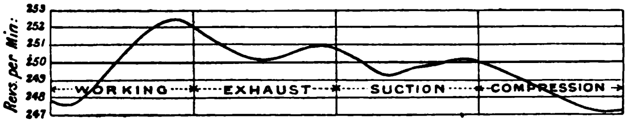
The variation of speed during a cycle is reduced by two heavy fly-wheels instead of one keyed on the crank-shaft, as shown by the velocity curves, Fig. 3, taken from an Otto cycle gas engine of single cylinder, 8·5 inches diameter by 10 inches stroke, running at 250 revolutions per minute and driving an electric lighting dynamo.

The influence of the inertia of the reciprocating parts, giving maximum speed after mid-stroke, is also seen by the curves, Fig. 3. The efficiency of the governor is increased by the additional fly-wheel. High speed tends to reduce the fluctuation during a single cycle, by adding to the power of the fly-wheel. On account of the danger of bursting by centrifugal force, and to allow a large factor of safety for the tensile strength of castings, a cast-iron fly-wheel should not exceed a rim speed of 100 feet per second, a high value being 75 to 80 feet per second. The common rim speed varies from 50 to 65 feet per second, depending on the size and design of wheel, made in one casting. Wrought-iron, or built-up fly-wheels, and small cast-iron wheels hooped with steel, may be safely run at much higher speeds.

The tendency is to construct large power gas engines of two single-acting horizontal cylinders, placed either end to end on opposite sides of the crank-shaft, or two cylinders in tandem, with one heavy fly-wheel supported by an outer bearing at one end of the crank-shaft, which is directly coupled to the dynamo. For example, the large Premier tandem scavenger engine, developing upwards of 650 indicated horse-power at 128 revolutions per minute with Mond gas, has two cylinders of 28⅛ inches diameter by 30 inches stroke, and one fly-wheel, the rim weighing 24 tons, of 12 feet effective diameter, and 36 inches broad. With a mean effective pressure of 100 lb. per square inch during explosion, the variation of speed is less than 1 per cent.



Gas Engine with two Fly-Wheels



Gas Engine with one Fly-Wheel.

Fig. 3.—Cyclical Variation of Speed.

In an engine of 100 horse-power driving a three-phase alternator, the field-magnet is attached to the crank-shaft and serves as fly-wheel for the engine.

High-speed vertical engines are also built with two or three cylinders, as in a marine engine, and a heavy fly-wheel at each end of the crank-shaft, which is directly coupled to the shaft of the dynamo for electric lighting.

The improved regulation of speed for steady continuous running night and day, combined with the increased efficiency and commercial economy of large gas engines using cheap fuel gas requiring only 1 lb. of coal per brake horse-power-hour, points to the future usefulness on a still larger scale of the internal combustion engine as a prime mover.

The *petroleum engine* is also made to run at high speed with heavy fly-wheels of about four times the governing power of those a few years ago put on engines to drive dynamos for incandescent lamps. These self-contained motors are specially suitable where there is no supply of gas, and motive power is required up to 25, 50, and even 100 horse-power. **High compression** has not quite the same advantageous effect as in the gas engine, owing to (1) the condensation of the oil vapour under pressure in some engines, and (2) the tendency to pre-ignition. The latter may be prevented by the use of the electric and *hot-tube ignition*, and by increasing the cooling surface of the combustion chamber and vaporiser, to regulate the temperature for *automatic ignition* at the desired pressure. As in the gas engine, the difficulty is to keep the large masses of metal exposed to the flames from getting too hot.

Five years ago some petroleum oil engines worked best on American and others on Russian oil, probably due to the fact that makers designed their engines to suit one particular oil, being influenced in their choice by such questions as market price of the oil and facility for obtaining an assured supply. Some engines thus made to use American "Royal Daylight" have not been so successful with Russolene. However, the best modern oil engines are adapted to use either American oil or Russolene, which require a different temperature and compression. Thus in the Hornsby-Akroyd oil engine there was facility for varying the compression of the charge before ignition, by compression-plates fitted at the end of the connecting rod next the crank-pin, to shorten or lengthen the connecting rod. The most suitable compression under given temperature conditions can best be found by experience. Heavy Russian astatki, with flashing point about 300° Fahr., requires a lower compression and ignites with greater readiness than benzoline or light petroleum spirit, which readily evaporates at atmospheric temperature. Benzoline also requires higher compression for automatic ignition, and develops more power than Russolene for a given size of cylinder. On the other hand, experience shows that Russolene allows of a higher compression and gives 15 to 20 per cent. more power, with better results in most engines, than the lighter oil American Royal Daylight.

The consumption of oil per horse-power-hour becomes lower as the power of the oil engine increases, but not so rapidly as in the gas engine. The author has made careful brake tests, each of 3 hours' duration at full load, on Hornsby-Akroyd oil engines of 5 and 25 brake horse-power. The oil used was Russolene, having total calorific value of 20,286 B.Th.U. per lb., and after deducting the latent heat of the steam in the products of combustion, the effective heating value of the oil as used in the engine cylinder is 19,100 B.Th.U. per lb. The smaller engine gave 6 indicated horse-power and 5 brake horse-power on 4·8 lb. of Russolene per hour, at the rate of 0·8 lb. per indicated and 0·9 lb. per brake horse-power-hour. The 25 brake horse-power engine ran easily at a mean of 31 indicated and 26·74 brake horse-power on 19·5 lb. of Russolene per hour, equal to 0·63 lb. per indicated and 0·73 lb. per brake horse-power-hour. During the six hours' run of this engine at full load and two-thirds load, the mean speed was 202·5 revolutions per minute, and the greatest variation was from 201·2 to 203·2 revolutions per minute.

After a continuous trial run of nine hours' duration with varying loads, this 25 brake horse-power engine maintained a steady speed of 203 revolutions per minute for more than fifteen minutes with a load of 39 brake horse-power, or 56 per cent. above its rated power. The thermal efficiency of the engine is $\frac{2545}{0\cdot63 \times 19100} \times 100$, or 21 per cent., that is, the efficiency of the vaporiser and engine, which corresponds to the combined efficiency of gas producer and gas engine.

The useful work done on the brake is $\frac{2545}{0 \cdot 73 \times 19100} \times 100$, or $18 \cdot 1$ per cent. of the effective heating value of the oil.

The difference, 2·9 per cent. of the heat, is absorbed in engine friction, and the mechanical efficiency is 86 per cent. Exactly half of the heat is rejected to the cooling water in the jacket around the cylinder; and the remainder, 29 per cent., is rejected as heat in the exhaust gases and lost by radiation. The exhaust gases were clear and colourless, and the chemical analysis indicated that the oil was completely burned. The cost of the Russolene oil used per hour per brake horse-power, was 0·36*d.* at full-load, and 0·4*d.* at two-thirds load. The efficiency obtained compares favourably with the best performance of many gas engines, and is twice that of a good steam engine.

The use of petroleum and its products in various forms, for heating and motive power purposes, has received much attention during the last ten years.

There are at least four ways in which petroleum is used in prime motors:—

1. Heavy refuse oils, as a substitute for coal, are injected as *fuel* with steam and air under steam boilers, where the price of coal is high and the liquid fuel cheap and plentiful.

2. *Naphtha* or petroleum spirit, may be readily evaporated and used exactly in the same way, and instead of steam as *working substance* in a type of engine precisely similar to the steam engine. In Yarrow's spirit launch, ordinary heavy oil is used as fuel to evaporate the naphtha which is completely enclosed, whilst the naphtha-vapour takes the place of steam as the working fluid in the engine, being condensed and used over again.

3. Both *fuel and working substance* for the internal combustion engine, as in modern petroleum oil and spirit engines. These are rapidly replacing small gas and steam engines, because they are self-contained, efficient and economical prime motors, and petroleum can be obtained in almost any country village. Oil gas is also used in the gas engine.

4. Mineral oils, manufactured from crude petroleum, are

used as **lubricants for the bearing surfaces**, piston an cylinder of the internal combustion engine. Good continuou lubrication is most important for steady running, to keep th bearing surfaces in good condition and prevent any tendenc of the metals to seize or become welded together by over heating from abrasion, to reduce wear and tear, and the grea waste of fuel consumed in overcoming the frictional resistanc offered to the relative motion of the surfaces working togethe in the mechanism.

In designing bearings of sufficiently large area for the given pressure and with soft white metal in the brasses attention must be paid to the method of applying * the oily and greasy lubricants between the rubbing surfaces. A bearing should be an easy fit for the shaft. The brass should be cut away at the sides to reduce friction and avoid pinching or seizing the shaft, and to allow the oil access to that part of the bearing where the pressure is greatest. The wear of the brass always takes place on the "off" side of the bearing, where the lubricating film is thinnest and tends to make the radius larger than that of the journal, and when bedded, improves lubrication. The ends of the brasses are rounded off, so that the shaft may yield or bend slightly without undue pressure on the edge of the bearing.

The lubricant keeps two moving surfaces apart by forming between them a thin oily film, which reduces the frictional resistance so that the metallic surfaces work together smoothly and float over each other.

Experiments by Mr. Beauchamp Tower and Professor J. Goodman show that a steel shaft in a gun-metal bearing, when dry, seizes with a load of about 80 lb. per square inch, whereas *with perfect lubrication by sperm oil there is no metallic contact between the bearing and shaft running at steady speed* until the pressure of about 600 lb. per square inch increases the temperature so as to seriously reduce the viscosity of the oil and cause seizing. In one case Professor

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* See Experiments by Mr. Beauchamp Tower, *Proc. Inst. Mech. Engineers*, 1884, 1885 and 1891; and by Prof. Osborne Reynolds, *Phil. Trans. Royal Society*, 1886.

Goodman by measurement found the thickness of the oil film to be 0·0004 inch. With a suitable oil for the given pressure and speed, scizing may be prevented between a steel shaft and a bearing lined with soft white metal, kept clean and properly lubricated.

Experience shows that the frictional resistance does not depend alone upon the true fitting and nature of the different metals forming the bearing surfaces, but also largely upon the nature of the lubricant in the oily film that keeps them apart —upon the thickness, "body" or viscosity, adhesiveness and capillarity, as well as the greasy, unctuous and lubricating properties of the film. In fact, at moderate speeds, with perfect lubrication, the bearing surfaces are wholly separated by a thin continuous film of oil, and the resistance to relative motion is not so much between the metal surfaces as between the particles of the lubricant.

The results obtained in everyday work under service conditions afford the best test of a lubricating oil suitable for the given *temperature*, *pressure* and *relative speed* between the surfaces. If we find in practice the kind of oil most suitable for the lubrication of different parts of an engine, there are a few simple physical and chemical tests of the quality of the oil which we may apply to a fresh sample.

A serious objection to animal and vegetable oils as lubricants is their tendency to take up oxygen from the air, to become oxidised, producing heat, and gumming. In this way cotton waste, saturated with these oils, when thrown in a heap exposed to the air in a warm room, gets heated, and may cause spontaneous ignition and combustion. Pure mineral lubricating oils are free from this tendency to oxidise when exposed to the atmosphere, and do not gum or corrode the metal surfaces of bearings. The heat in gas engine cylinders partially decomposes fatty oils into stearic and oleic acid, and pitch. Heavy mineral oils, of thick body and high volatilising point, are not so decomposed by heat in the cylinder, only become black and thinner, suffer little change by use, and when filtered or strained can be used over again for ordinary bearings. The presence of free acid in oil is highly objectionable.

In practice it is found that the use of a small percentage, about 5 per cent., of refined neutral fatty matter such as tallow oil greatly improves the lubricating power of mineral oils in the gas engine cylinder.

For cylinder lubrication special thick mineral oils should be used of specific gravity 0·890 to 0·910 at 60° F., with flashing point (Pensky-Martens) not below 400° to 550° F., and with very slight loss of weight by evaporation in air at 400° F. Price's heavy gas engine oil and "motorine" give satisfactory lubrication.

In the Priestman oil engine the heavy hydrocarbon oil, condensed from the oil vapour during compression of the charge, lubricates the cylinder and contributes to the smooth running of that engine, although the consumption of oil is slightly increased.

To secure good lubrication, engines are fitted with lubricators for supplying oil automatically to the cylinder, piston, crank-pin, and the various moving parts. In special cases the crank-shaft or other part is made hollow and cooled by water circulation, to keep up the viscosity of the oil and prevent it being squeezed out of the bearings. When dry-metal surfaces of bearings are forced together, without lubricant between them, abrasion and tearing of the metal occurs at the point of contact, and the overheating of the bearing surfaces tends to weld the metals together, causing seizing troubles and stopping the engine. Dust and dirt with grit in a bearing has the same effect, and requires immediate attention and examination when undue heating is observed, to prevent serious injury to the bearing. For a *hot bearing*, an excellent lubricant consists of clean fine white lead mixed with finest genuine sperm oil. When the engine stops, ease the sides of the brasses to prevent them pinching the shaft, and to allow the oil free access to the bearing surface.

In order to prevent gummy deposits in the gas engine cylinder, valves and passages, use special thick mineral oils of great body and viscosity, of high volatilising point, and that have little loss by evaporation at the average temperature of the cylinder walls.

CHAPTER II.

HISTORY OF THE INTERNAL COMBUSTION ENGINE.

Early Inventions.

IT may be said that the history of HEAT ENGINES begins with the discovery of cannon: the first internal combustion engine used at Crecy. This should rather be regarded as a *gunpowder engine* which performs work in driving a shot by the expansion of the gases formed and the heat developed by the *explosion* of the gunpowder. Here the working substance and fuel, gunpowder, possesses potential energy which, on ignition of the compressed charge by a spark and by subsequent combustion, is converted into kinetic or heat energy.

Gunpowder Engines. — In 1678, the ABBÉ HAUTEFEUILLE *proposed* to raise water by means of the explosion of gunpowder. The idea was *to produce power from the explosion indirectly by using atmospheric pressure.* The gunpowder was exploded in a vessel, and a *partial vacuum* formed by cooling the products of combustion. This vacuum was used to suck up and raise water from a reservoir by the pressure of the atmosphere. Hautefeuille does not appear to have put his proposals into practice, nor ever to have had such a machine actually constructed.

The earliest gunpowder engine constructed to do useful work was invented by HUYGHENS in 1680. This was also the *first* use of a *cylinder and piston* in a heat engine. The piston was at the top of a vertical cylinder which was filled with air. When a charge of gunpowder, placed at the bottom of the cylinder, was fired, the air and products of combustion in the cylinder were forced through valves which opened outwards, and then a partial vacuum was formed by the cooling of the gases that remained in the cylinder. The piston was forced down into this vacuum by atmospheric pressure, as in later atmospheric gas engines.

In 1688 DENIS PAPIN, the inventor of the safety valve, described Huyghens' machine to the Royal Society and in the 'Proceedings' of the Leipsic Academy; and in 1690 he improved the valves in order to produce a better vacuum. But he found that, by the explosion of the gunpowder, and after cooling of the gases, about one-fifth part of the air still remained in the cylinder, and its elastic force opposed the free descent of the piston under atmospheric pressure. Such apparatus was exceedingly rude, and the risks of accidental explosion with gunpowder so great that no successful results were achieved. Papin sought by another way,* the condensation of steam in the steam-engine cylinder, to produce that perfect vacuum he had failed to obtain by the use of gunpowder under a piston.

During the next hundred years the steam engine mainly engaged the attention of engineers, and the designs that follow are too closely on steam engine lines.

Barber.—The next step was the important discovery that by the distillation of coal an inflammable gas is evolved. The first to manufacture coal gas and practically use it for lighting purposes was William Murdoch, a Scotchman living at Redruth, in Cornwall. He afterwards improved his process of manufacture, and in 1798 the Bolton & Watt Soho Factory, near Birmingham, where he was employed, was for the first time lighted with coal gas. The streets of London were first lighted with coal gas in 1812, and Paris in 1815. Still it was only to be had in a few large towns, and its usefulness only became known gradually.

The earliest attempt to obtain motive power from inflammable gas derived from the distillation of coal, and at the same time one of the first practical uses or applications of coal gas, was that of an Englishman, JOHN BARBER, who, in 1791, obtained a patent No. 1833 for "*an engine for using* INFLAMMABLE AIR *for the purpose of procuring motion.*"

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* Papin's inventions are given in his *Life and Correspondence with Leibnitz and Huyghens*, by Dr. E. Gerland, Berlin, 1881.

Barber heats *coal, wood, oil,* or any other combustible substance in a metallic *retort*, and conveys the vapour or gas to a *receiver*, where it is collected and *cooled* by a surrounding cistern of water. By means of an air pump and *compressor*, he forces this inflammable gas and atmospheric air, in *proper proportions*, through separate pipes into another vessel called the *exploder*, Fig. 4. Here the mixture is ignited, and "rushes out with amazing force and velocity" in a continuous stream against the vanes of a paddle-wheel, thus driving them round rapidly, working the pumps, and communicating motion to any machinery. The fluid stream is increased both in volume and velocity by water injected or pumped into the exploder through a small pipe. This water is also intended to *cool* the pipes and mouth of the *exploder*, besides forming steam. He also mentions in his patent that the fluid stream may be passed out at the stern of a ship, and thus propel the ship by the reaction against the water. In Barber's engine we have combustion of gas or inflammable vapour at constant pressure.

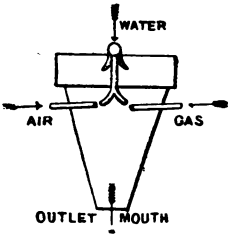

FIG. 4.
BARBER'S EXPLODER.

Street.—On the 7th May, 1794, ROBERT STREET took out a patent No. 1983 for the *first workable internal combustion engine with a motor cylinder and piston.* A solid iron piston is made to fit the iron cylinder, and is connected to a pump or other machinery to be driven. A stove keeps the bottom of the cylinder hot. As soon as it is sufficiently heated, a small quantity of spirits of turpentine or petroleum is dropped on the hot part of the cylinder and is converted into inflammable vapour by the heat. The piston is then raised by a lever, and draws air into the cylinder to mix with the gas or vapour. During its up stroke the piston also raises an external flame to a touch-hole in the cylinder, and fires the mixture of vapour and air. The explosion forces up the piston, and with it a long rocking beam or lever which also descends with the piston in the return stroke and at its far end works a pump to raise water. At the end of the down stroke the piston is guided into the cylinder and displaces the products of combustion. Here we have a description of the process of vaporising the petroleum in modern engines, of drawing in the charge of air by the suction of the piston, and of ignition by external flame; but the mechanical details appear crude and imperfect, and although the ideas were good as carried out later on, nothing satisfactory was obtained in practice. The piston had to be lifted by an attendant every stroke, to prepare and fire the charge, so that the engine could not be self-acting.

Lebon.—In 1799 and 1801, PHILIP LEBON, an ingenious French engineer, patented a gas engine in which we find the *first suggestion* of the *compression* of the *mixture of gas and air before ignition*; indeed, the first compression gas engine combined with a gas-producer. Lebon has a gas retort or furnace, for the production of lighting gas from coal. He distils the carburetted hydrogen and other gases from coal, and stores them in a reservoir. Then he proposes to use this gas in an engine practically similar in construction to one of the most successful pioneer gas engines, the Lenoir, brought out in 1860, but without the pumps and compression.

By means of the motor piston Lebon drives two double-acting pumps, and compresses a measured charge of gas with a charge of atmospheric air separately into a receiver. Here the constituents get mixed, and the mixture is introduced into the motor cylinder alternately on each side of the piston, and fired by the electric spark. The products of combustion expand, driving the piston backwards and forwards, doing work on the two sides alternately, as in a double-acting steam-engine cylinder. Both the pumps and the electric machine are driven by the engine.

The design of this gas engine is remarkable, showing an advance far ahead of the time. Coal gas had not been introduced for lighting purposes, its manufacture was only in its infancy, and the expense of preparing it specially for the engine would be too great; besides, the only source of the electric spark known at that time was static electricity, which was very uncertain and dependent on atmospheric conditions. Lebon was assassinated in 1804, before the details of his invention were completely worked out. Sixty years later, his ideas on gas engines were realised and reproduced.

Brown's Atmospheric Engine.—SAMUEL BROWN invented, in 1823, the first gas engine that unquestionably did actual industrial work and was a mechanical success, although a cumbrous, bulky machine for its power.

It is an *atmospheric* engine, with water-jackets to cool the cylinders. A gas flame is kept constantly burning outside the cylinder port, and ignites a mixture of inflammable gas and air as it enters the cylinder. Gradual and continuous combustion takes place below the piston during the up stroke. The air and part of the burning and expanding gases are allowed to escape through valves in the piston. Then, by suddenly cooling the products of combustion by a jet of water pumped into the cylinder, a *partial vacuum* is obtained and the *atmospheric pressure* outside *drives down the piston.* In his first patent, No. 4847 of 1823, Brown describes three applications of this principle to different kinds of machinery: the first, to turn a water wheel; the second, to raise water; and the third, to drive pistons.

Fig. 5 shows a sectional elevation of the arrangement for this last purpose.

This engine is double-acting, a piston being connected to each end of the cross-beam or rocking lever by a rod and chain. The arrangement somewhat resembles Newcomen's atmospheric engine. B B' are the outer cylinders, open at their tops; A A' the working cylinders, each with piston P having the valve V opened at the top by rod *r* from the spiral spring *s s'*; *v v* very small valves in the upper side of V; *j* gas jet communicating with the gas supply box Q by the pipe *a*; *b* gas burner constantly lighted to ignite gas at *j* through the orifice *o* when uncovered by the slide *d* actuated by tappet T on piston rod *k* of the double-acting pump S, which forces water from cistern C into the water-jackets and over the cylinders. Some water falls through the valves V′ V′ to bottom of the cylinders, whence it returns to the cistern through the syphons shown in diagram ; but experience showed these were unnecessary. K is connecting rod from rocking beam to crank-shaft K with fly-wheel W ; *t t′* are arms which move tube M con-

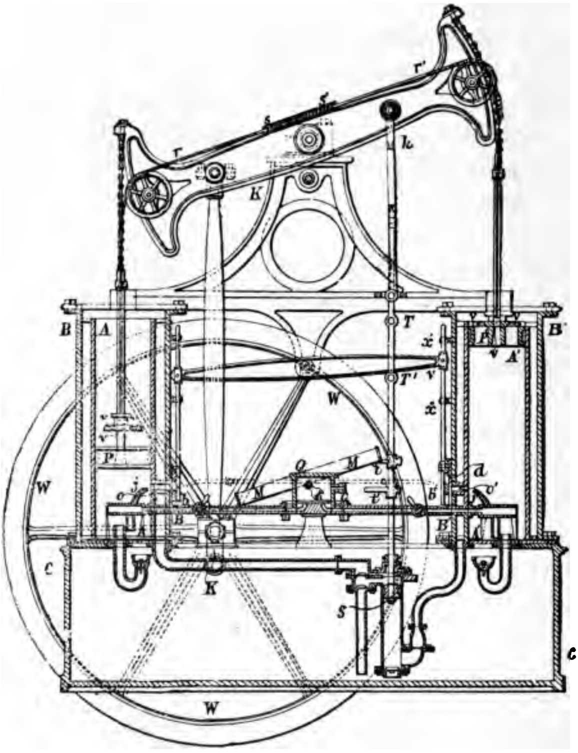

FIG. 5.—BROWN'S ATMOSPHERIC ENGINE, 1823.

taining mercury, and turning the forked arm or tumbler F which moves the slide over the orifice *a* or *a′*, thus regulating the supply of gas to the working cylinders from the box Q, With the piston P in its lowest position (as in the left-hand cylinder, Fig. 5), the valve V is held open by the action of the springs *s s′* ; the slide is off the orifice *a*, allowing the gas to flow through the pipe into the burner *j*, where it is ignited through the opening *o* by the flame *b* outside the cylinder; whilst in the other cylinder A′ the piston P′ is at the top, the valve V′ and the orifices *a*′ *o*′ are closed.

As the piston P is moved upwards, the tappet T comes down against the little beam, draws the slide *d* over the orifice *o* and opens *o*′. A strong flame continues to burn the gas at *j*, whilst the mercury flows along the tube M, turned by the tappet *t*, and the tumbler F moves the slide over the orifice *a*. Continuous combustion of the gases is obtained without explosion. Part of the rarefied air in the cylinder A escapes through the piston valves. When the piston has reached its highest position the valve V is closed, and by this time the pump S has forced water through the passages and over the top of the cylinder. This suddenly causes a partial vacuum beneath the piston, and as the external atmospheric pressure drives it down, the orifice *o* and the valve V are re-opened. Now the piston P′ is at the highest part of its stroke; and a similar series of operations goes on in both cylinders, the pistons working alternately.

Subsequently, in patent No. 5350 of 1826, Brown improved his machinery, and used auxiliary cylinders in which the air and gas were mixed before being drawn into the motor cylinder and fired in order to obtain a continuous vacuum. Brown had worked long and hard, but only achieved temporary success and pecuniary reward. His engine attracted much attention and admiration, a number were made and used for years chiefly to raise water and to propel boats and barges on canals, as at Croydon, Eagle Lodge, and other places.* In some experiments on the Thames, from Blackfriars Bridge, a speed of seven or eight miles an hour was attained.

A company was formed and hydrogen gas was used; but the expense of procuring gas was found to entirely prevent its application to prime motors instead of steam, and hence the company was dissolved, although Brown was still sanguine as to ultimate economy in the working of his engine.

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* See full account in the *Mechanics' Magazine*, vols. ii. 1824; iv. pp. 19 and 167; vii. 1827; xvii.; and xviii.

Wright.—In 1833, W. L. WRIGHT patented a vertical double-acting gas engine, in which the combustion products of a mixture of gas and air act directly on each side of the piston, like the steam in a steam-engine cylinder. The drawing in his patent, No. 6525, shows very complete details of the working parts, and usual devices of connecting rod and crank for transmitting motion from the piston to the rotating shaft and fly-wheel. The cylinder has a water-jacket, and water passes down the interior of the piston rod and piston, to keep them cool. Double-acting pumps compress the gas into one reservoir, and the air into another.

A *centrifugal governor* controls the admission of the charge of gas and air, under pressure of about 2 lb. per square inch above atmospheric, into the combustion chambers, so that the total quantity may remain the same and be mixed in proper proportion for doing the work. These combustion chambers are spherical cylinders, one fixed near each end of the working cylinder, and the mixture is lighted at a touch-hole by a small flame kept constantly burning. The intention was to have an explosion every stroke, and the piston actuated by the expansive force of the gases. But this force would be greatly diminished by the condensation of the gases in contact with the cold sides of the cylinder, piston, and rod. It does not appear that this engine was ever made to work.

Barnett.—The patent No. 7615 of 1838, granted to WILLIAM BARNETT, an iron founder of Brighton, Sussex, marks a decided advance in the history of the gas engine, being much more carefully thought out and the details better illustrated than any preceding one.* Three forms of vertical gas motors, fixed on tables, are described; the first is single-acting, and the other two double-acting. An important feature of Barnett's engines is the *compression* of both air and gas by separate pumps into a receiver at a pressure of about 25 lb. per square inch. Also in the third form without a receiver, the explosive mixture is delivered from the pumps direct into the motor cylinder, and the motor piston completes the compression of the charge in the motor cylinder itself before ignition. The pumps are driven from a shaft geared by spur wheels to the main crank shaft, so that the pumps make twice as many strokes as the motor piston. In the double-acting type the compressed gas and air are admitted alternately on each side of the piston. The compressed charge is fired by the ignition cock at the commencement of each stroke, when the crank is passing the dead centre. The explosion drives the piston through the whole of its stroke; and the other side of the piston discharges the burnt gases through the exhaust during the first half of the stroke.

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* See drawing of Barnett's gas engine in the *Proceedings of the Institutir Mechanical Engineers*, 1889.

Some of the products of combustion remain in the cylinder and mix with the compressed gas and air supplied from the separate pumps as the exhaust port is closed by the motor piston, which compresses the fresh charge during the remainder of the stroke. When the piston commences its next stroke the compressed charge on its other side is fired, and the products from the previous explosion are swept out as before. Some of these remain in the cylinder and increase the pressure.

A special feature of this engine is the igniting cock, which appears to be the first instance of ignition of the charge in a gas engine by a flame, enclosed and re-lighted by an external flame, so extensively used for half a century. The igniting apparatus consists of a conical cock, sectional elevation Fig. 6, into which is closely fitted a hollow revolving plug containing a gas burner. This small gas jet inside the plug is lighted by an external flame through a port in the cover, as shown at the side. There is one other port in the cover opening to the motor cylinder at the back. The hollow plug has only one side aperture, which, in the position shown in Fig. 6, opens to the atmosphere, allowing free circulation of air through the plug, so that the outside flame ignites the inner gas jet. As the plug is turned on, the opening is completely closed by the cover, and the flame is kept alight in it until the opening in the plug comes opposite the explosion port in the cylinder. Part of the compressed charge of gas and air then enters the hollow plug, to strengthen and spread the flame rapidly, thus firing the charge in the motor cylinder.

The explosion usually extinguishes the flame in the hollow plug, which remains closed until it is turned further round and opens to the atmosphere through the lighting port, where the gas jet is again lit by the external flame. The hollow plug is also cleared of the residual products by the free circulation of the air. The external flame must be protected from draughts of air, for if blown aside it may fail to re-light the jet inside the plug, consequently the charge would not be fired, and the engine would soon be brought to a standstill.

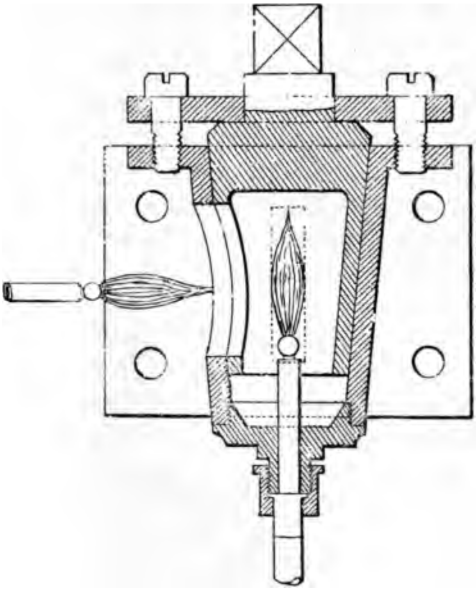

FIG. 6.—BARNETT'S IGNITION COCK.

Barnett's engine is similar in several points to the Clerk gas engine, which was brought out forty years later. The engine was made and sold, proving more successful in this respect than many that came after it.

Hydrogen Gas Engines.—About this time we find a number of patents for hydrogen motors. The great cost of hydrogen and oxygen gas make them all mere curiosities.

For example, in 1841, James Johnston describes a machine which might be called a *condensing gas engine.* In order to obtain power he would introduce an explosive mixture of hydrogen and oxygen under a piston in a motor cylinder, and then fire the charge by an electric spark, driving the piston up to the top of cylinder. Immediately after the explosion a vacuum is produced by condensation of the steam formed, whilst another explosive mixture is introduced and fired above the piston, driving it down, utilising the effect of the vacuum. The engine would thus be double-acting, the explosive mixture being drawn in, ignited, and the steam formed condensed, alternately above and below the piston.

Other devices were proposed by Robinson, in 1843; Reynolds, 1844; Perry, 1845; Brown, 1846; Roger, 1853; Bolton and Webb, 1853; Edington, 1854; and others.

These proposals serve to mark the ideas on the subject at the time. In 1858 De Grand suggested the compression of the charge in the cylinder by the motor piston, but the mechanical details were not practical and the idea was abandoned.

Drake's Ignition Engine.—A remarkable gas engine was exhibited by Dr. ALFRED DRAKE at Philadelphia in 1843, and again, with improvements, in New York Crystal Palace in the year 1855.* Patents: in United States, No. 12715 of 1855; also in Great Britain, to A. V. Newton, No. 562 of 1855.

Dr. Drake's "*ignition engine*" is like a double-acting horizontal steam engine, but more bulky for the same power. It has a cylinder 16 inches diameter, a piston making stroke 18 inches, and connected to a crank-shaft on which there is a heavy fly-wheel. To prevent over-heating and facilitate lubrication the piston and piston rod are made hollow, the cylinder is surrounded with the water-jacket, and through all of these a stream of cold water circulates.

In order to ensure the proper proportion—one part of coal gas to nine or ten times its volume of atmospheric air—a regulating valve to the gas pipe from the supply reservoir and the ignition supply pump is arranged so as to cover an opening to the gas pipe and also a much larger opening to the atmosphere. The power of the engine may be regulated by a throttle valve in the gas supply pipe, controlled by a governor.

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* See *Mechanics' Magazine*, vol. xxxix., Sept. 1843, p. 304; *The Civil Engineer and Architects' Journal*, 1856, vol. xix. p. 340; also *The Artizan*, April 1856, p. 87.

Mode of Ignition.—The electric spark being found impracticable, and a jet of gas extinguished at each explosion, the charge is fired by intensely heated metal tubes. Dr. Drake inserts near each end of the cylinder, at the points where it is intended to fire the charge, a tube of hard cast iron, 2 or 3 inches long, 1 inch internal diameter, ¼ inch thick, and directs into the cavity a constant blow-pipe flame from the outside, to keep the metal at a bright white heat. Iron is found to last longer than platinum, but at the best these igniters are liable to crack and get destroyed in a short time by the hot gases. This appears to be the *first* instance of ignition by metal tube heated by an external flame.

The *action of the engine* is as follows :—

The explosive mixture is drawn into the cylinder at atmospheric pressure during one-third of the stroke. The valve is then closed, and the piston uncovers a port to a small recess in the side of the cylinder, and allows the mixture to be fired by the hot iron tube. An explosion follows, and the products of combustion instantly expand, exerting a pressure of about 100 lb. per square inch or upwards, and the piston is driven forward, giving motion to machinery.

The engine was designed to be double-acting, but at New York it worked single-acting, the valves at one end of the cylinder being allowed to remain always open to the atmosphere.

The products of combustion, when cooled, occupy nearly the same volume as before explosion, so that the great increase in bulk is due to the heat evolved by the rapid combustion.

The pressure on the piston at the moment of explosion was never accurately tested by indicator; but the engine could work up to 20 horse-power at a speed of 60 revolutions per minute, when single-acting, the mean effective pressure during stroke being 36·5 lb. per square inch. Theory would indicate an absolute pressure of 150 lb. per square inch at the moment of explosion. This is rapidly reduced by the cold water-jacket and metallic enclosure.

The gas employed is from the street mains, the same as used for lighting, but the quantity consumed during any special test is not given. Dr. Drake mixes this gas with pretty nearly its combining weight of oxygen. The explosion is violent; much of the force is suddenly expended on the cylinder heads, and shakes the whole machinery with great violence, so that the action of the engine is unsteady, owing to defective construction.

Failure was invited by the attempt to make this gas engine of too high powers on steam-engine lines.

The engine was also worked with petroleum by mixing the vapour with suitable proportions of air.

Barsanti and Matteucci.—The next noteworthy invention is that made by EUGENE BARSANTI and FELIX MATTEUCCI. The patent, dated 13th May, 1854, is entitled, "Mode of Applying the Explosion of Gases as a Motive Power." In their patent, No. 1655 of 1857, these two Italians describe an ATMOSPHERIC ENGINE with a *free piston* —the *first of this type.* In the first plan, besides the free piston, an auxiliary counter-piston works a slide valve to draw the charge of air and gas into the cylinder between the pistons, and drives out the products of combustion. The charge is fired by a series of electric sparks, and the free piston is projected upward, being out of connection with the shaft. The *whole energy of the explosion is thus utilised* in doing work, by rapidly driving up the piston, overcoming frictional resistance, its own weight, and the pressure of the external air, until the piston stops. The greater part of the energy of the explosion is stored up as work done in raising the piston before the heat is lost by cooling, and the burning gases have long and rapid expansion. A partial vacuum is formed in the cylinder below the piston by the water-jacket, which rapidly cools the products of combustion, and the piston, being also acted upon by the atmospheric pressure and its own weight, begins to descend. It is then made to do actual work by means of a rack on the piston rod which gears into a spur wheel on the fly-wheel shaft with ratchet and clutch gear to drive the motor shaft only during the descent of the piston, and which allows the latter to fly perfectly free during its ascent.

Some idea of this engine may be gathered from Fig. 7, given in the original patent No. 1655 of 1857. A is the cylinder, open at the top and containing the principal working piston P, with rack on the rod R gearing into the spur-wheel L, which runs loose on the main shaft K, but carries the click C pressed by the spring *s* into the teeth of the ratchet-wheel B, which is keyed on the shaft K. When P moves upwards, the wheel L, carrying *s* and C, turns to the left freely on the shaft K; when P falls, L is turned to the right (clockwise) and, gearing into B, causes the main shaft K to rotate.

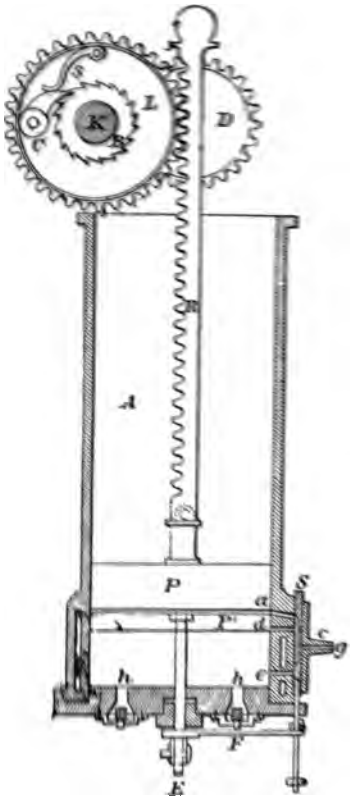

FIG. 7.
BARSANTI AND MATTEUCCI FREE PISTON GAS ENGINE.

Below the principal piston there is another, the counter-piston P', with rod E attached by a cross-head to two lever-bars (not shown in figure) driven by two eccentrics on adjoining shaft, and which receive their motion from the main shaft by the wheels D. Thus the counter-piston receives a regular up-and-down movement, so arranged that the downward stroke of the counter-piston P' cannot take place until the flying-piston P has reached its lowest position.

The cover on the lower end of the cylinder is provided with two valves *h*, *h* opening upwards. The lever F attached to the counter piston actuates the slide valve S, and also closes the electric circuit.

Starting with the *free piston* P in its lowest position, and the counter-piston P′ in its highest (as in figure), in the first place P′ goes down, and to fill the vacancy between the pistons, air is drawn in through the passages *a*, *b*, and *c*. Soon the arm F moves down the slide S, closing the air port *c*, and opening communication between the gas supply *g* and the cylinder through the ports *d* and *b*. Gas is drawn in between the pistons, until the downward motion of the slide S closes *g* and opens *e*.

At this moment the mixture is ignited by a series of electric sparks, explosion takes place, the piston P is shot upwards free, and the counter-piston clears the bottom of the cylinder through the foot valves. The water-jacket cools the expanding gases, causing a partial vacuum, when the piston P turns and comes down, driving the main shaft and the fly-wheel, the counter-piston P′ begins its up stroke and drives out the products of combustion until the port *d* is closed. Then the remaining products between the two pistons are forced out through the passages *a*, *b*, *c*, and the first position is again reached. To obtain uniform motion two working cylinders are employed, and the pistons act alternately on the same shaft, carrying a fly-wheel of suitable size and weight.

The *second* and simplest form of this engine has a single vertical cylinder, provided with only one motor piston, like P, free in its upward stroke when projected by an explosion of a gaseous mixture beneath it in the cylinder. The rod R has a rack which works into the toothed wheel L, Fig. 8. K is the motor shaft, bearing a fly-wheel. A pawl upon the wheel D engages the ratchet only on the down stroke of piston, and drives the motor shaft, but on the up stroke it slips on the ratchet, so that the shaft revolves continually in the direction of arrow in Fig. 8. The cams *c* and *d*, operating tappets upon the rack, serve to raise or lower the piston.

The exhaust valve is at the base of the cylinder. When the products are expelled the piston is raised a little, so as to draw in a fresh charge of air and gas. The piston next closes the inlet valves, and the charge is ignited by sparks from a De la Rive multiplier in circuit with a Bunsen battery.

The explosion shoots the free piston *rapidly* upwards in the cylinder, giving several times the usual expansion of the gases, and when the whole energy is spent in lifting the piston, and the burnt products are cooled by the water-jacket, the piston is forced downward by its own weight and the pressure of the atmosphere into the partial vacuum, preserved by the cooling of the gases, which helps to pull down the piston, and thus uses the energy stored up in it to drive the motor shaft.

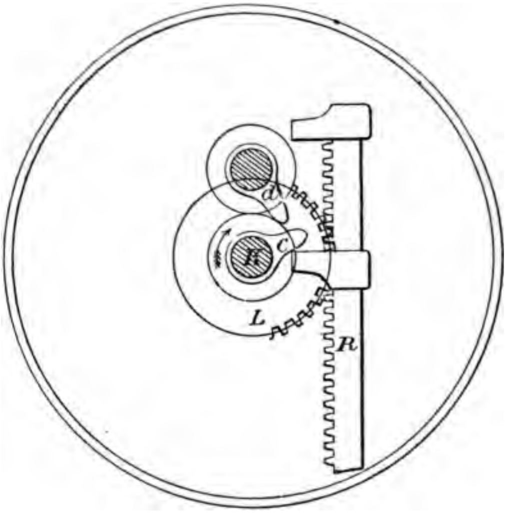

FIG. 8.—RACK AND DRIVING GEAR.

This atmospheric motor was the forerunner of the well-known Otto and Langen free-piston engine, which it closely resembled in external appearance, principle, and mode of working, although the latter was made a practical and commercial success. Why the Barsanti and Matteucci engine did not reach the practical stage can only be accounted for on the hypothesis that the inventors were not good practical mechanics, and therefore unable to apply the discovery they had made. This should teach future inventors the lesson to stick to a good idea and make it a practical success rather than merely resting satisfied with the notion that it is good.

CHAPTER III.

EARLY PRACTICAL GAS ENGINES.

Non-Compression Type.

Lenoir.—In 1860, PIERRE LENOIR invented and introduced the first practical gas engine that came into public use, and attracted the attention of the industrial and scientific world. This pioneer gas engine, Fig. 9, had little of novelty except that it was made to work successfully in small powers of half-horse, one, two and three horse-power only. Its mechanical details were thoroughly worked out, and its action was smooth, silent and steady, without shock from the explosions.

Lenoir's patent in France is dated 24th January, 1860; and in England, No. 335 of 8th February, 1860. After four months ten engines were at work in Paris alone, and twenty-five more ordered. The engine was at first made by Hippolyte Marinoni in Paris. These engines were carefully constructed and finished, and worked well, but got spoiled by undue praise and commercial "puffing," representing the Lenoir as being much better than actual practice showed. Exaggerated reports as to the cost of working in comparison with the steam engine, and ludicrously inaccurate statements of its small consumption of coal gas were made, which set a bad example for the future. The Lenoir gas engine craze spread and its popularity increased. True, the real advantages of this new motor were evident: easy to fix, and ready to work wherever there was a gas supply, it occupied little space, and there was no boiler. It could be very easily started or stopped at a moment's notice, and gave silent, smooth and regular running. It was thus a handy motor, suitable for many purposes where small power was required, and, above all, for intermittent work.

The Lenoir engine was used to propel a boat on the Seine, and was put to all sorts of work—driving water pumps, printing and lithographic machines, lathes, cutting chaff, and for various industrial purposes.

Without any exact idea or proof of the actual cost of working, many persons procured a Lenoir gas engine to whom probably a steam engine would have been better suited. So great was the demand that in three years 130 engines were sold and at work in Paris alone; and in five years between 300 and 400 were made in France.*

A company formed in London purchased the Lenoir patents for Great Britain, and 100 Lenoir engines were made by the Reading Iron Works Company. Some of these engines are still at work. An engine of one horse-power pumped water at Petworth for more than twenty years.

The London Company stated: "The consumption of gas does not exceed 60 feet per horse-power per hour, costing, with gas at 4*s.* 6*d.* per 1000 feet, and including battery and other expenses, 3½*d.* per hour."

According to the Paris Company, "an engine of one horse-power uses two cubic metres (70 cubic feet) of coal gas per hour.

These engines were not made quite so well. They were found to be noisy; they did not work so steadily; got out of order and occasionally stopped, due to over-heating, want of lubrication and cleaning; so that, although they did not need heating, they did need oiling frequently. Worst of all, the average gas consumption in brake tests was 104 cubic feet (the lowest 96 cubic feet, and as high as 146 cubic feet) of coal gas per horse-power per hour. This excessive consumption of gas proved the early statements as to cost of working to be inaccurate and misleading. The result was that many of these engines were abandoned, and the natural reaction set in—the new gas engines were decried, although several of them have worked well, and are in good condition at the present day. The half horse-power Lenoir engine in the Patent Office Museum, South Kensington, is a good example. In 1865 the Curator, Mr. F. P. Smith, found that at 110 revolutions per minute it gave just one horse-power, and worked in the workshop most satisfactorily. The cylinder is 5½ inches diameter and 8½ inches stroke.

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* *Practical Mechanics' Journal*, August 1865.

The LENOIR ENGINE (1860), Fig. 9, is horizontal and double-acting, like a steam engine. During the first part of each stroke the piston draws into the cylinder, at atmospheric pressure, the air and gas which mix in the admission valve port. Admission is cut off at about half stroke, and the explosive mixture closed up in the cylinder is ignited by the electric spark. The explosion causes a rapid rise of pressure in the expanding gases, and forces the piston to the end of the stroke. The pressure falls by the expansion of the gases doing work on the piston, and the cooling action of the cylinder walls. Near the end of the stroke the exhaust valve opens, and the products of the combustion are expelled during the return stroke. The energy stored up in the fly-wheel drives the piston forward during the suction part of each stroke, and the explosion during the remainder of it ; at the same time expelling from the cylinder the burnt products of the previous explosion on the other side of the piston. This operation is repeated every stroke, and exhaust takes place exactly as in a double-acting steam engine.

The sectional plan Fig. 10, shows in diagrammatic form the general arrangement. The cylinder A, water-jacketed at every available point, contains the piston B working the connecting rod C and the crank-shaft F, connected thereto by the cross-head D and the fork E. The gas and air are admitted by the inlet slide valve G, and the products of combustion escape to the exhaust through the outlet slide valve H on the opposite side of the cylinder. These slide valves are driven by separate eccentrics J and K on the crank-shaft, and work between the cylinder faces and covers held by screws against the valve faces.

Water circulates through the cylinder-jacket from a cooling tank or the water main, and sometimes by a small pump The gas supply pressure is kept steady by an india-rubber gas bag fixed on the supply pipe, as used with modern engines.

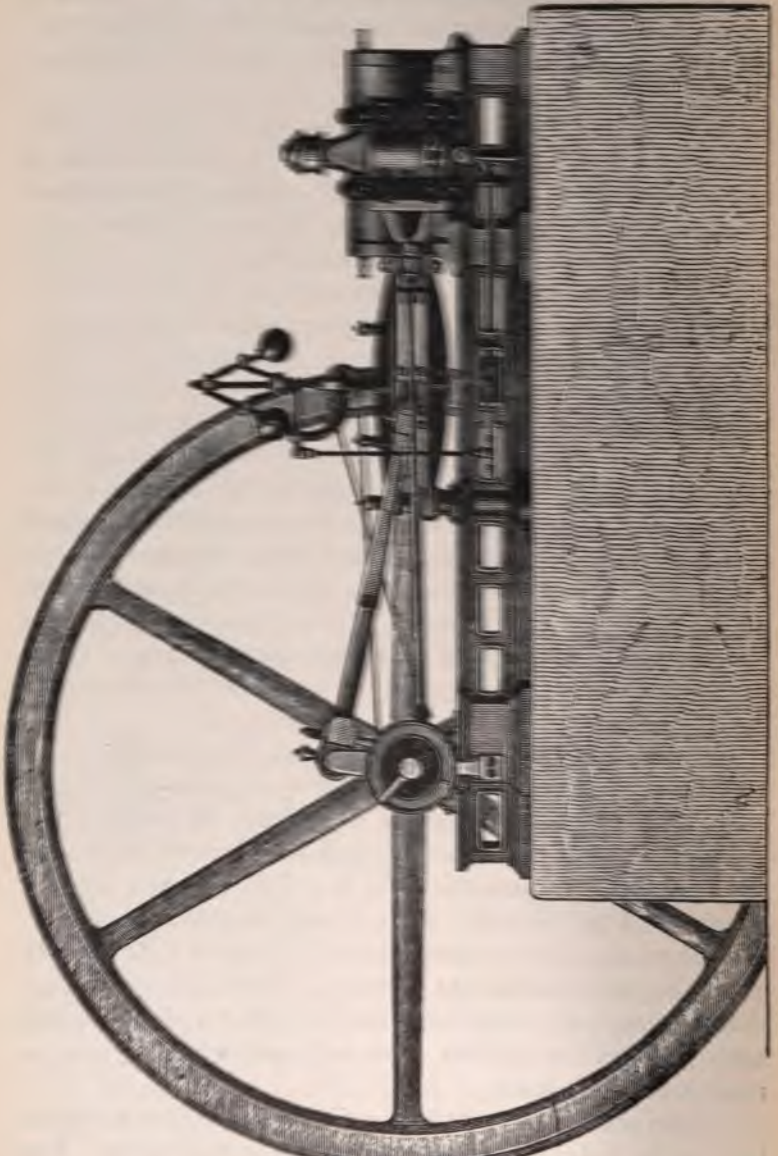

FIG. 9.—2 H.-P. LENOIR GAS ENGINE, 1860.

Fig. 11 is a partial plan, with a horizontal section, and Fig. 12 is a transverse vertical section of the Lenoir engine cylinder. The cylinder A, cast with the water-jacket, has two surfaced faces, upon which work the two slide valves G and H, which open and close alternately and at the proper time the admission ports *a a* for conducting the mixture of air and gas to each side of the piston, as well as the exhaust ports *b b* for the rejection of the products of combustion.

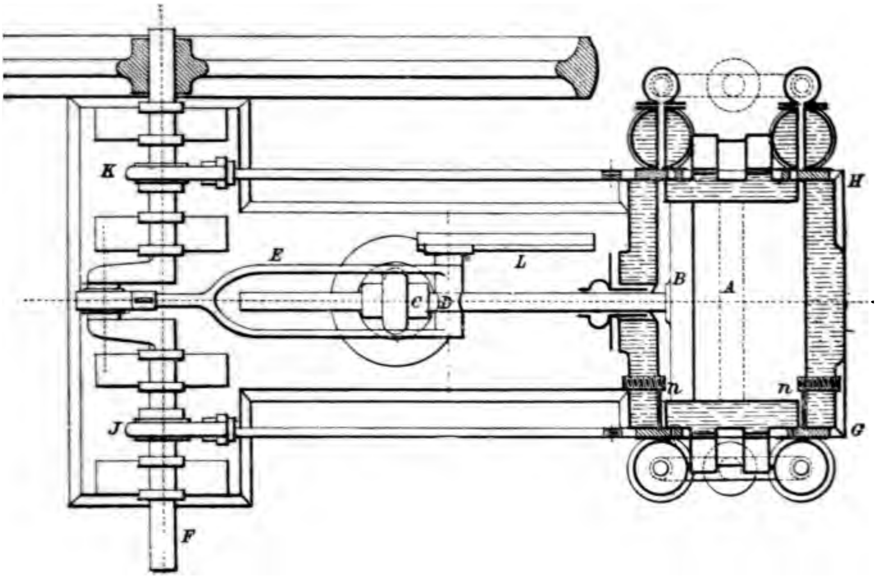

Fig. 10.—Lenoir Horizontal Gas Engine, 1860.

The slide valve G, which regulates the inlet of air and gas into the cylinder, is provided with one gas-admission port, which communicates with one or other of the two rows of holes *b, c,* Fig. 13, made in the brass plate. This plate carries the two cocks *r, r,* which admit the gas from the forked pipe. The air is admitted through the port *a*, which is made large to prevent throttling, and in communication with the open nozzle, surrounded by a cap, as shown in Figs. 11 and 12. The outlet slide H has only two slots, which are brought opposite the cylinder exhaust ports shortly before the end of the stroke, to allow the products of combustion to escape.

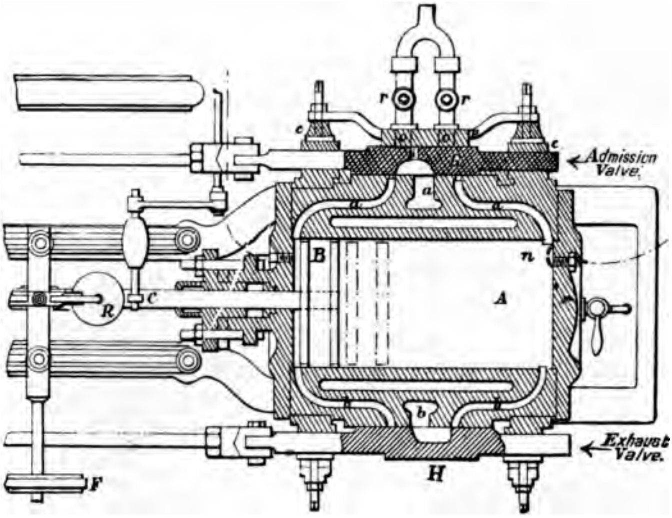

FIG. 11.—LENOIR ENGINE CYLINDER (HORIZONTAL SECTION).

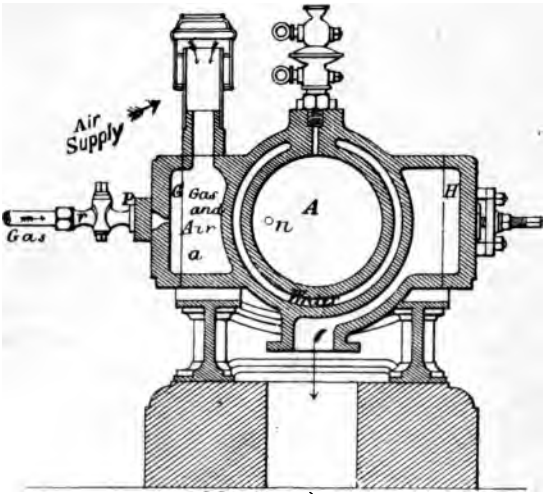

FIG. 12.—LENOIR ENGINE CYLINDER (TRANSVERSE VERTICAL SECTION).

The inlet slide, Fig. 13, is of brass, grooved up at the ends, and pierced with round holes *b*, *c*, through which the gas enters the cylinder from the gas channels.

Fig. 14 is a cross section, taken through the line of holes opposite either of the two main ports in the cover, showing the larger rectangular passages for the admission of the air between the round gas ports. The gas and air are mixed thoroughly by thus entering the cylinder in numerous separate streams. This facilitates ignition by the electric spark between the ends of two wires at *n*, Fig. 11. A battery of two Bunsen cells is used, with a Ruhmkorff induction coil and a commutator. The *electric igniter n n* placed at each end of the cylinder, consists of a hollow brass plug screwed into the end covers of the cylinder, and having a porcelain or other suitable non-conductor in the form of a short rod fixed inside it. In this rod are placed the wires required to produce the spark; the one wire is in contact with the hollow metal plug, and the other is insulated by the porcelain in the plug, but in electric communication with one of a pair of small insulated plates or segments of a commutator. The positive pole of the battery is in connection with a third insulated segment, whilst the negative pole of the battery is in electric communication with the metal work of the engine. The electric circuit is closed by making contact with one or other of the pair of

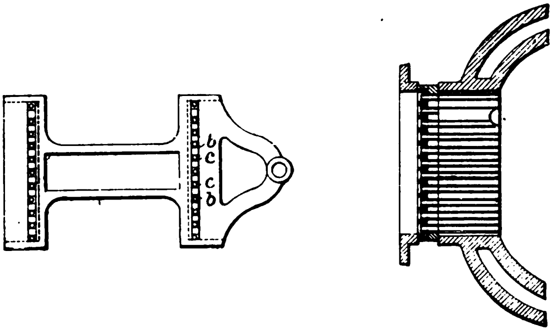

FIG. 13.—ELEVATION. FIG. 14.—SECTION.

LENOIR ADMISSION SLIDE.

small insulated plates or segments and the third plate; this is done by a metal slide carried by the cross-head of the piston rod, kept in contact with both plates. The segments are adjusted so that the electric spark from the induction coil passes between the platinum points at either end of the cylinder, just as the gas admission valve closes at that end. When a short circuit occurs to cause a miss-fire or late ignition, the platinum points of the igniters must be cleaned and dried. This is a weak point which gives trouble in practice.

The heavy fly-wheel drives the piston B forward from its position in Fig. 11, and draws in a charge of air and gas in the proportion of about nine to one. The air port opens to the cylinder before the piston completes its previous stroke, and after that the gas port opens. The gas supply is regulated by a throttle valve and centrifugal *governor* R, Figs. 9 and 11, which alters the proportion of the mixture between six to one and twelve to one, so varying the rate and strength of the explosion until complete cut off. This proved very inefficient, as there was very little range to work on owing to want of compression, and the weak mixture gave late or retarded combustion or none at all, causing very irregular explosions. The inlet slide G closes when the piston has travelled about half the length of its stroke, causing the pressure behind the piston to fall slightly below that of the atmosphere. The mixture is then fired by a series of electric sparks; the pressure suddenly rises to about five atmospheres. The water-jacket has cooled the products of the previous combustion in the cylinder before the piston, and these are driven out, when the exhaust port H opens, at a pressure of about 1·5 atmosphere.

During the return stroke a mixture of air and gas is drawn in through G behind the piston, ignited at half stroke, and, as before, the burnt products on the other side of the piston are expelled into the exhaust at a temperature of 600° to 800° C.

In the half horse-power engine the temperature of the escaping gases is about 200° C. The engine is made to run from 45 to 130 revolutions per minute. The piston speed varies from 74 to 170 feet per minute.

Trials.—Professor Tresca tested the earliest form of the Lenoir engine at Paris, in January 1861. The ½ horse-power had a cylinder 7·1 inches in diameter and 4 inches stroke, and running at 130 revolutions per minute it gave 0·57 horse-power on the brake with a consumption of 112 cubic feet of Paris coal gas per horse-power per hour. The air and gas were in the proportion of ten to one, and the maximum explosion pressure reached 4·87 atmospheres. The loss of heat through the cylinder walls to the water-jacket was 53 per cent. of the total heat of combustion of the gaseous mixture.

The one horse-power engine cylinder was 9½ inches diameter by 4¾ inches stroke. At 94 revolutions per minute the effective load was 0·90 horse-power, and the gas consumption reduced to 96 cubic feet per horse-power per hour. Air and gas were mixed in the ratio 7½ to 1, and the maximum pressure was 5·36 atmospheres. Only 4 per cent. of the whole heat generated is converted into useful work on the brake, 66 per cent. of the total heat is taken away by the water surrounding the cylinder, whilst of the remaining 30 per cent., part escapes with the discharged products of combustion, and the rest is lost in shocks, friction, conduction, and radiation.

Indicator diagrams of the two horse-power Lenoir engine, 8 inches diameter and 16 inches stroke, are shown in Figs. 15 and 16.* Three explosion curves are given in Fig. 15.

The mode of firing the charge was unreliable, irregular, and defective. Sometimes the electric spark failed to explode the mixture, and the late uncertain ignitions in Fig. 16 were objectionable.

Before explosion, the throttling by admission port reduced the pressure in the cylinder to 3 or 4 lb. per square inch below atmospheric. The maximum pressure in the cylinder due to explosion was 63 lb. per square inch, and the mean effective pressure during the stroke about 8 or 9 lb. per square inch.

Mr. Slade gives the maximum temperature after ignition at about 1356° C., and says: "The dotted lines represent the theoretical curve of expansion, taking into account the loss of heat and consequent fall of pressure due to the work done (which is the proper theoretical curve for an indicated diagram). The temperature at the end of the stroke, indicated by this line, would be 1180° C. The final temperature shown by the diagram, supposing no leakage, is 781° C."

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* *Journal of the Franklin Institute*, vol. lxxxi. (1886), p. 175, 'The Lenoir Gas Engine,' by Fred. I. Slade.

Serious trouble in working arose from over-heating of the cylinder and piston. The latter often became red hot and heated the charge before ignition. The expansion of the working parts on heating prevented them being air-tight when cool, and rendered delicate adjustment of the slides difficult, especially the exhaust. The cylinder was liable to be scored and cut up, owing to heating, unless a large quantity of water was kept flowing round the water-jacket, and even then the piston soon became unduly heated. Besides, the cylinder and ports required daily cleaning.

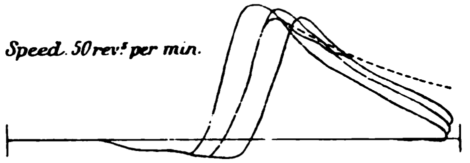

Fig. 15.—Indicator Diagrams from Lenoir.

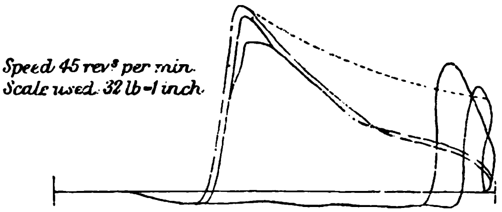

Fig. 16.—Indicator Diagrams from Lenoir Engine.

Owing to the great cooling effect of the water-jacket surrounding the cylinder, one would naturally expect the expansion curves to fall more rapidly below this adiabatic line. The sustained pressure, keeping up the expansion curves, is ntly due to the evolution of heat whilst the piston is moving. This clearly points to dissociation after the explosion, followed by re-combination of the gases as the piston advances and the temperature falls.

As the piston travels at a comparatively slow pace, the explosion and consequent expansion of the gases cause a sudden force on the piston, more of the nature of a blow than of a steady pressure. The inventor tried to remedy this apparent defect, by admitting the air and gas in a stratified form, in order to obtain slower combustion and have a less sudden but better sustained pressure.

In his patent specification of 14th January, 1861, Lenoir proposes to inject *a little steam or water spray into the cylinder* at the same time that the "*air and gas enter and remain in the cylinder in regular strata or layers.*" The water spray takes up part of the heat generated by the explosion, and by evaporation aids in the expansion, at the same time keeping the working parts cool and acting as a lubricant. But the presence of a little steam, while greatly assisting the chemical combination of an explosive gaseous mixture, makes the explosion sudden and violent, and renders ignition irregular and difficult.

The erroneous idea was, by stratification and steam injection, to avoid sudden explosion, to obtain more gradual combustion, and thereby improve the economy—"increasing the effect of the engine."

Hugon.—About this time, PIERRE HUGON, director of the Paris Gas Company, was doing his utmost to obtain motive power by the explosion of a mixture of gas and air. His patents in the years of 1858, 1860 and 1863 show how he tried to produce a partial vacuum by the energy of the explosion, and to utilise the atmospheric pressure.

In 1865 HUGON patented a direct-working and practical engine of the *vertical* type, with an ordinary cylinder and piston, double-acting, and in principle very like the Lenoir, with the important improvement of a flame ignition instead of the electric spark.

Hugon used a slide valve carrying two internal jets, supplied with gas under slight pressure, each lighted by a gas jet kept constantly burning outside the cylinder. This slide valve brings the flame opposite the cylinder ports, and there ignites the rich portion of the explosive mixture; the flame strikes back into the cylinder and fires the charge at the proper time.

Another distinguishing feature was *the injection of water into the cylinder to cool it.* This water absorbed part of the heat suddenly generated by the explosion, protected the cylinder and piston from over-heating, and was proposed to reduce the violence of the action; whilst, being changed into steam, it aided the expansion and sustained the pressure better during the stroke, thus effecting a decided economy in both the oil and gas consumption.

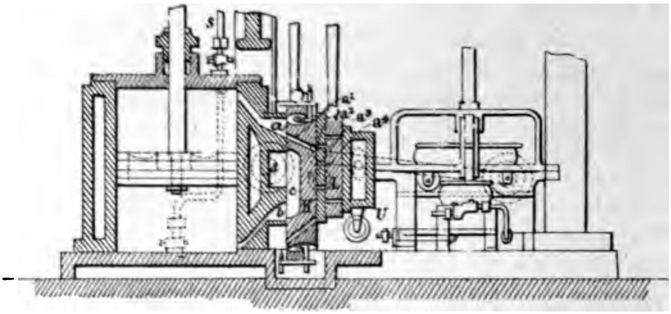

FIG. 17.—HUGON GAS ENGINE, 1865.

Fig. 17 is a sectional elevation showing only the piston and valve arrangement in this Hugon engine. The action is as follows:* As the piston is driven in the first part of its down stroke by the fly-wheel, it draws in above it an explosive charge from the mixing chamber U, fed by the bellows pump or by an india-rubber bag; at the same time it expels the products of the previous combustion from the lower part of the cylinder by *b, c, d,* as in the steam-engine exhaust. When the piston has travelled about one-third of its stroke, the main slide valve K descends and suddenly shuts the communications a_1 a_2 a_3 a_4 between the admission port a and the mixing chamber U; at the same time the igniting flame, from the upper gas jet carried in the slide, is projected into *a* and causes the explosion. The same operations occur on the other side of the piston in its up stroke.

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* French Patent, No. 66,807, 29th March, 1865.

It will be observed that the distribution is effected by two slides : the inner one K, actuated by an eccentric on the crank shaft, serves for admission, exhaust, and ignition ; the outer slide L, suddenly actuated by a cam, controls the supply of the explosive mixture from the chamber U, so as to secure a rapid opening of the ports for admission of the mixture, as well as a rapid cut-off at the proper time, just as the igniting port in K brings the flame to fire the charge.

During each stroke a pump injects a small quantity of water spray into the cylinder through the supply pipe S at the instant of explosion, for the purpose of reducing its violence and to cool and lubricate the cylinder.

In order that the feed may not be affected by the varying pressure in the gas main, the air and gas are mixed in a fixed india-rubber bellows pump. A smaller bellows pump, worked from an eccentric on the crank shaft, supplies the gas reservoir which feeds the four ignition flames. It can be moved by hand to ignite the gas jet in the slide before starting the engine, and this is done by turning the fly-wheel. The rubber bellows gave trouble by leakage, and in some cases were replaced by metal pumps with mixing valve.

Hugon also designed a horizontal type, as described (French patent, No. 117,390 of 7th March, 1877), being the final form adopted in practice. The Hugon engine was exhibited and sold in considerable numbers in and about London. A small one (half horse power) may still be seen in the Patent Office Museum, South Kensington ; the cylinder is $8\frac{3}{16}$ inches diameter and 10 inches stroke.

The Hugon was considered an improvement on the Lenoir. In it we have the first successful application of ignition by gas flame carried in a slide valve, so extensively used afterwards. The flame ignition gave certainty of action, and the water injection improved lubrication and kept the cylinder and piston cool, even during a day's continuous run, the engine doing heavy work smoothly and with great regularity. The slide-valve arrangement was ingenious but complicated; the ports were liable to get stopped easily, and required frequent cleaning.

The indicator diagrams, Fig. 18, show how closely the cycle of operations agrees with the Lenoir. With the flame ignition weaker mixtures can be used, hence the retarded explosion and more prolonged expansion, although great economy could not be expected without compression.

Trials of the Hugon motor by Professor Tresca, at Paris, on the 7th of February, 1866, gave the following figures: The engine cylinder was 13 inches in diameter, and the stroke 12¾ inches. During a 5 hours' run, speed 53 revolutions per minute, piston speed 112 feet per minute, maximum pressure 3·27 atmospheres, with mixture 1 vol. of gas to 13 vols. air; temperature of exhaust gases 186° C., temperature of water-jacket 42° C.; giving out 2·07 brake horse-power with a gas consumption at the rate of 91 cubic feet per hour per brake horse-power. The indicated horse-power was 3·55, and the gas consumption 53 cubic feet per indicated horse-power per hour. Assuming the heating value of the gas to be 727 B.Th.U. per cubic foot, Tresca reckons that 7·1 per cent. of the heat is turned into work in the engine cylinder; 23·6 per cent. carried off by evaporation of water in the cylinder; and 20·1 per cent. lost through the cylinder walls to the circulating water in the cooling jacket.

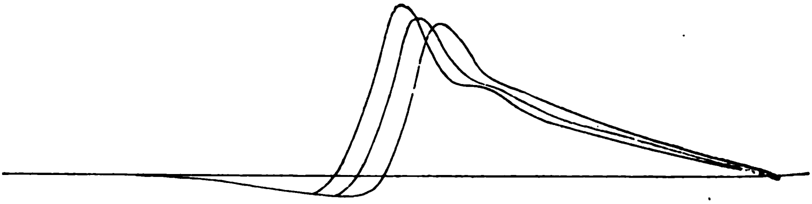

FIG. 18.—HUGON INDICATOR DIAGRAMS AT 60 REVOLUTIONS, 1 INCH = 32 LB.

In another trial the Hugon engine had a gas consumption of 74 cubic feet per indicated horse-power per hour. This engine, having a cylinder 13 inches diameter and 12·75 inches stroke, worked with a piston velocity 108 feet per minute, and had mechanical efficiency 0·58. The mixture of air and gas was in the proportion 13·5 to 1, the maximum pressure 3·8 atmospheres, and the gases escaped at 190° C.

Otto and Langen.—Meanwhile two Germans, OTTO AND LANGEN, were working with unwearied activity to overcome gas-engine difficulties. Their idea was to avoid at least some of the effects resulting from the shock of the sudden explosion by first storing up the energy without allowing it to act directly on the machinery, and then to utilise it, as well as the partial vacuum that would follow.

In 1863 Otto patented an engine embodying this principle and the free flying piston. At first two pistons were tried, but abandoned in favour of the 1866 engine with one free piston.

Whilst designing their engine these inventors were guided by the following considerations. "In igniting combustible gases inside a closed metallic vessel, the heat generated is imparted to the gaseous products of combustion, which, if prevented from expanding in consequence of increased temperature, will exert a proportionate pressure upon the inner surface of the closed vessel. This pressure would remain constant if no heat were taken away from the gases, but it will in reality diminish rapidly in consequence of the heat generated being absorbed by the metallic surfaces of the vessel. Experience has shown that the interval of time which elapses between the heating and consequent expanding of the gases, and the subsequent cooling and consequent contraction, is but a very short one, and therefore, in applying the expansive force of such heated gases as motive power, unless they are allowed to expand very rapidly—immediately after combustion has taken place—a great portion of the heat which should have produced such expansion will be absorbed by the cylinder of the engine, and consequently a great portion of the motive power will be lost."

Hence they very properly arrange to make the explosion and expansion of the gases take place with great rapidity, so as to allow very little time for heat to be given out to the cylinder walls, whilst the gases are cooled rapidly by the great expansion, and the heat energy is mainly expended in shooting up the piston and rack like a projectile.

After the pressure of the burning gases in the cylinder has fallen to atmospheric, the energy of motion is spent in carrying the piston still higher in its flight, pushing back the atmosphere. This prolonged expansion of the burnt products and the cooling action of the water-jacket together form a partial vacuum in the cylinder, which allows the piston to fall, under the action of gravity and atmospheric pressure, spending the energy of the explosion slowly in doing work.

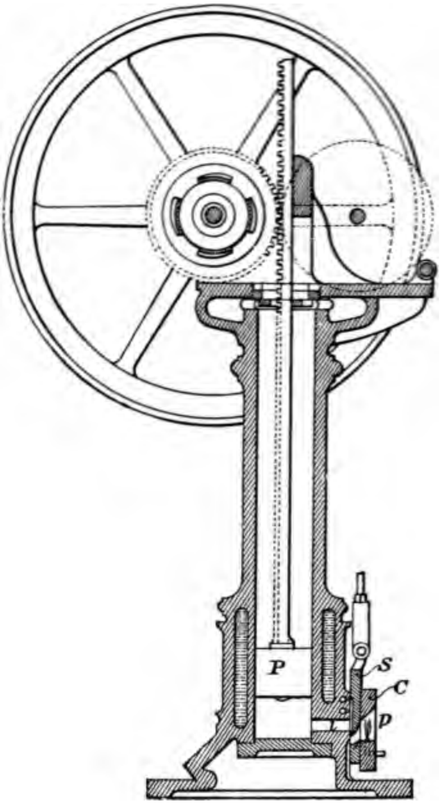

FIG. 19.—OTTO AND LANGEN ENGINE.

In 1866 these ideas assumed a practical shape — the famous OTTO AND LANGEN *atmospheric and free piston engine*, which was made known to the world through the Paris Exhibition of 1867. The machine was identical in principle and the same in general construction as that invented ten years earlier by Barsanti and Matteucci, but the details were worked out so completely as to attract attention by the noisy irregular action, and at the same time to work with far greater economy than any previous form of prime motor. This free-piston engine, of strange appearance, necessarily bulky for its small power, and somewhat resembling a pile-driver in action, was made a practical commercial success. It was certainly much more economical of gas than the Lenoir and Hugon motors which it superseded, and held the field about ten years.

The Otto and Langen motor proved practically useful for small industries and for domestic requirements, and the German firm at Deutz, near Cologne, made and sold more than 5000 of them in about ten years. Many of these are still to be found doing regular work in this country. The author recently inspected an Otto and Langen in a cycle shop, where it had done good work for many years. There is also one in the Engineering Museum, University College, Nottingham.

Here we have a very tall vertical cylinder open at the top and containing one piston P, whose rod has teeth gearing into a spur-wheel on the fly-wheel shaft, driving it by means of *clutch gear* only during the down stroke. The piston is shot upwards by the explosion, the toothed wheel running perfectly free on the shaft. The quantity of charge is fixed so as only to throw the piston to the top of the cylinder, where rubber buffers are fitted to take the blow from too strong an explosion. A small auxiliary shaft to the right, thrown into gear with the main shaft by a ratchet and pawl worked by the centrifugal ball *governor* lever, actuates the slide valve S, which admits the charge below the piston, carries a gas flame to fire it at the proper time, and allows the burnt products to escape.

The centrifugal governor regulates the speed by throwing the slide valve out of gear entirely, and so prevents admission of gas and air when the speed is too high. The governor may also be fixed to throttle the exhaust, checking the down stroke of the piston and reducing the number of strokes until the speed is brought down to the normal.

In 1867 improvements were made in the spur-wheel to work on the driving shaft and in the coupling or clutch gear, to give greater freedom of action during the ascent, and greater certainty of gearing without backlash during the descent of the piston, as well as in the arrangement of eccentrics and levers on the shaft to regulate the slide-valve movement and to lift the piston while it is sucking in the charge.

The construction of the distributing slide S, with ignition chamber, is seen in Fig. 20. This slide is worked from the small auxiliary shaft by the rod (shown broken, Fig. 19) and is pressed against the valve face by the slide cover C and spiral springs under the nuts of its fastening screws. The charge of gas enters by the passage *h*, the air by *i* through the slide cavity *k* and the passage *l* below the piston. When the slide S is in its lowest position, a mixture of gas and air flows into the chamber *m* through the passage *o*, and is ignited by the gas flame *p* in the slide cover. Now as the slide moves up this lighting port *m* is closed, and carries the burning mixture opposite *l*, when a tongue of flame, shooting through *l*, fires the mixture in the cylinder.

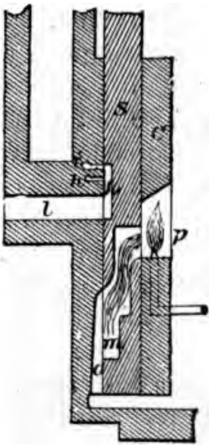

FIG. 20.—SLIDE VALVE.

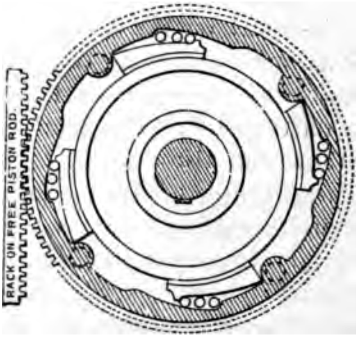

FIG. 21.—OTTO AND LANGEN CLUTCH.

The ingenious *clutch* or *coupling gear*, shown in elevation, Fig. 21, is the chief feature of the invention. The inner central part is rigidly keyed to the main shaft. Around this is a double disk, shown shaded, gearing into the piston rod rack. Between this outer disk and the inner rim there are four wedge-shaped steel pieces, on each of which three rollers run freely while the rack moves upwards, so that the outer disk then runs loose and in the opposite direction to the main shaft. On the other hand, when the piston and rack move down, the rollers are wedged between the steel pieces and the inner inclined surfaces of the shaded disk, thus locking together the toothed part and the inner one keyed on the motor shaft. Hence in its downward stroke the piston drives the motor shaft with fly-wheel. On the return upward stroke of piston and rack the rollers loosen the wedges so that the part with the teeth again runs loose.

The action of the engine is as follows:—

In the first place, the energy stored in the fly-wheel lifts the piston, sucking in, at a little under atmospheric pressure, a charge of gas and air from *h* and *i* through the slide *k* and passage *l*. At about one-tenth of the stroke this admission port *l* is closed by the slide, the charge is fired by the intermediate flame *m*, and the piston, with its rack gearing into the toothed disk, running free and loose on the main shaft, is shot up with great velocity, being gradually brought to rest by gravity and by the atmospheric pressure. The pressure below the piston falls in consequence of the cooling of the gases by the great and rapid expansion and by the water-jacket. After the piston reaches the highest point of its flight it falls down by reason of the atmospheric pressure and its own weight, whilst it drives the main shaft and does useful work. The back pressure in the cylinder below the piston, at first about ¼ atmosphere, gradually rises by compression to one atmosphere. Now the piston drives out the burnt gases, whilst it sinks further down by its own weight. The energy stored up in the fly-wheel again lifts the piston, and the same cycle is gone through.

The indicator diagram, Fig. 22, published by Mr. F. W. Crossley, enables us readily to follow the action throughout.

There are thus three operations:—

First, *g a*, Admission of the charge of gas and air.

Second, *a b*, Explosion at almost constant volume because of the heavy weight of piston, followed by expansion *b c d*; the piston being suddenly projected upwards by the expanding gases until the whole energy of motion is spent. The sudden explosion caused so great vibration of the indicator spring pencil that the line *b c d* can only give a vague idea of the pressure.

Third, *dfg*, Down stroke of the piston doing work by means of the atmospheric pressure and of gravity opposed by the back pressure, followed by discharge of the cooled products.

It will be observed that the negative work represented by area *fgaf*, corresponding to discharge of products and drawing in fresh charge, is relatively very small. The charge consists of one volume of coal gas to nine volumes of air; the pressure rises to four or five atmospheres, and the energy of the explosion is so quickly expended in giving the piston potential energy that very little heat is given out to the cylinder. This, together with the *very long range of expansion* (to more than ten times its original volume), explains the high efficiency of these motors. In fact, the Otto and Langen worked much more economically than any previous engine.

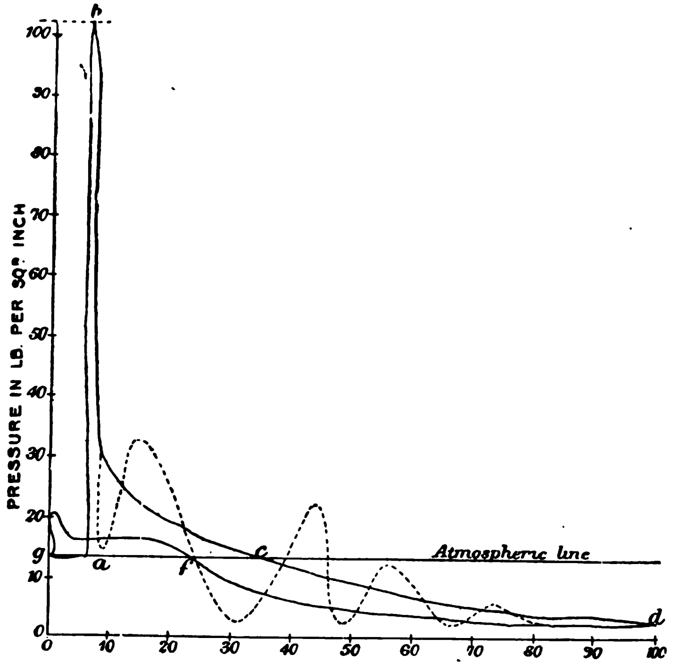

FIG. 22.—DIAGRAM FROM OTTO AND LANGEN ENGINE (FREE PISTON).

For small powers (about ½ horse-power) the gas consumption at first was about 44 cubic feet per hour per brake horse-power, which was reduced by improvements in the three-horse engine to 30 cubic feet per hour per brake horse-power. It is more satisfactory to know the consumption per brake or actual horse-power, for it is not clear how the indicated horse-power could be accurately calculated from the diagrams, since the mean pressure can only be vague and uncertain, owing to the vibrations of the indicator spring and the wavy curves traced on the indicator diagrams.

The number of explosions was only from about 20 to 40 per minute, depending on the load and power; and the speed of the crank-shaft 40 to 100 revolutions per minute.

Trials.—Professor Tresca tested the Otto and Langen engine of ½ horse-power at the Paris Exhibition in 1867. The cylinder was 5·9 inches in diameter, and at 81 revolutions per minute gave 0·46 brake horse-power; the consumption of Paris coal gas was at the rate of 44 cubic feet per brake horse-power per hour, not including that for ignition side lights, or a total of 48·7 cubic feet per brake horse-power-hour.

In 1868 Meidinger made a series of trials on a ½ horse-power engine which ran best at 75 revolutions per minute. The gas consumption varied from 29 to 49 cubic feet per horse-power per hour. Mr. D. Clerk tested a 2 horse-power Otto and Langen engine at Oldham in 1884. The cylinder was 12·5 inches in diameter, and the longest stroke of the piston 40·5 inches. When making 28 explosions per minute the maximum pressure was 54 lb. per square inch above atmospheric, with a mixture of one volume of coal gas to seven of air. The speed was 90 revolutions per minute, and engine gave just 2 horse-power on the brake, with a gas consumption of 42 cubic feet per brake horse-power per hour. The temperature of the exhaust gases was about 180° C., and when a cooling tank of 70 cubic feet of water was used for circulation through the cylinder-jacket, starting at a temperature of 15° C., after 10 hours continuous working it entered the water-jacket at 67° C. and left at 85° C. Tresca estimates that the jacket cooling water only carries away about 17 per cent. of the total heat of combustion.

This engine was not without some serious *drawbacks.* The rack and wheels made a great noise during the up stroke of the piston, and this noisy action was rendered very unpleasant to the ear by being quite irregular. At high speeds the noise became intolerable. As regards construction, the mechanism was of necessity heavy and cumbersome for the power, and its action was not satisfactory. Only small sizes of this engine could be made, because of danger from the flying piston projectile, from the shock and excessive vibrations set up by the reaction or recoil like a gun on firing the charge, and the consequent wear and tear. On this account it was necessary to have the engine fixed on a rigid foundation.

Notwithstanding the superior economy in gas consumption, these mechanical defects, together with the great bulk and weight of this motor, and especially its noisy, unsteady and irregular action, led the inventors to give up the free piston in favour of their well known compression engine.

Messrs. Louis Simon and Son, of Nottingham, first started the Otto and Langen engine in England in 1867. In 1868, Messrs. Crossley began to make this atmospheric engine.

Gilles.—In 1874, GILLES of Cologne constructed an *atmospheric engine with free piston,* designed to remedy the defects in the Otto and Langen by reducing the *noise* of the rack and clutch, as well as the force of *recoil* after every explosion. It has two pistons working in opposite directions in the same vertical cylinder. The lower or motor piston A is connected by rod and crank to the fly-wheel shaft; the upper piston B is free or loose. The slide valve for admission and ignition is worked off the main shaft by a cam arrangement.

As the working piston A descends from its highest position, it sucks in the mixture of gas and air between the two pistons; explosion occurs, forcing the working piston A onward to the end of its down stroke, whilst the free piston B is shot up; its ascent after a time is checked by the cushion of air above it in the cylinder, and in its highest position it is held fast by a clutch. In the meantime a partial vacuum has been formed between the pistons by the cooling of the burnt products, and the piston A is forced up by the atmospheric pressure. Ere A reaches its highest position B is let go, and falls, driving out the burnt products.

This motor was less noisy and more compact than the Otto and Langen, although not so economical, but its weak point lay in the clutch arrangement, which hindered its success. It was introduced into this country by Messrs. Simon, of Nottingham, in 1877, and exhibited at Paris in 1878. This firm has since made other forms of gas motor. (See pages 81 and 200.)

Hallewell.—In the engine patented by HALLEWELL in 1875, the atmospheric pressure is utilised indirectly. The explosion takes place in a vertical cylinder A, closed at the top by a large spring valve, and containing the free piston, which is driven up, and in falling forms a vacuum in this cylinder. This vacuum is then put into communication with the exhaust port of the slide valve on another vertical cylinder containing a double-acting piston, driven to and fro by the atmospheric pressure being allowed to act alternately on its opposite sides, like steam in a double-acting steam engine. A lever lifts the free piston to draw the charge into the cylinder A. The distribution is regulated by a rotating slide valve. This engine achieved but little success.

Bisschop Engine.—ALEXIS DE BISSCHOP, in 1870, 1872, and 1874, patented and constructed for purposes requiring only very small power an extremely useful and handy little gas engine of the vertical non-compression and direct-acting atmospheric type.

Fig. 23 gives a view, and Figs. 24 and 25 sectional elevations of the BISSCHOP engine, as improved by Messrs. Andrew, of Stockport, the English makers.

A long rod connects the crank on the driving-shaft with the cross-head of the piston rod, which is guided in the open hollow column above the cylinder. When the explosion takes place, this long connecting rod and piston rod are almost parallel, so that the piston then gets a direct pull at the crank without any side pressure on the guide and piston.

A cylindric piston valve *f*, Fig. 24, communicates with the lower part of the cylinder and controls the admission and distribution of the charge and the exhaust of the burnt products. It is worked by a rocking lever f^1, and eccentric f^2, fixed on the driving-shaft. There are two gas jets, Fig. 24; one *b* shoots a flame through a hole *a* in the wall of the cylinder, the other is placed beneath to re-light *b*.

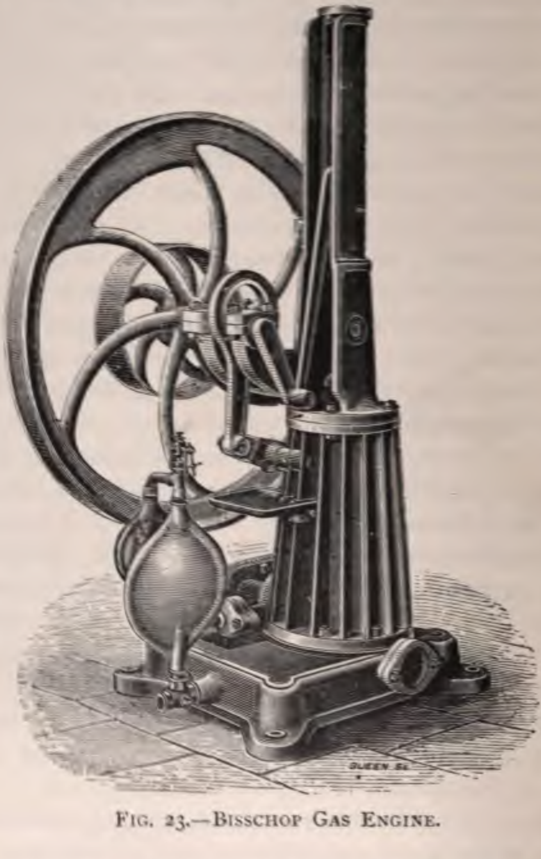

FIG. 23.—BISSCHOP GAS ENGINE.

The engine is fed from two india-rubber bags B, which serve as reservoir and regulator for the gas supply to keep the engine at the proper speed. There is no governor. The gas admission valve *d* consists of a thin iron disk, having holes covered with a circular sheet of india-rubber, which is sucked away from e disk, and allows gas to enter when pressure in cylinder is ss than that outside. Similarly the air valve *e* (Fig. 25) is pened by the air pressure outside, and closed by the explosion side the cylinder. Andrew adds an extra air valve by which ld air is drawn in at the commencement of the up stroke to ix with and cool the residual products in the ports. This fects a saving in gas consumption.

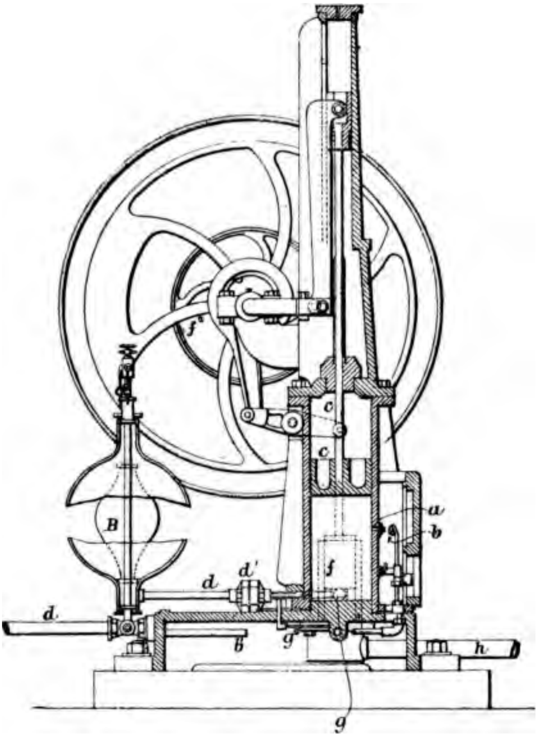

FIG. 24.—BISSCHOP ENGINE (SECTIONAL ELEVATION).

No water-jacket is required, as the engine is kept cool by number of radial flanges or brackets in the casting round the ylinder, which present a large cooling surface to the atmosphere, and give stability to the structure.

As the piston is raised, it draws in a mixture of gas and air at atmospheric pressure ; at about one-third of its up stroke the piston uncovers the lighting port (closed by a steel clack), the flame is sucked into the cylinder and fires the charge; and the piston is driven up rapidly to the end of its stroke. The energy thus stored up in the fly-wheel carries the piston through the down stroke, driving out the burnt products by the exhaust pipe *h*, and one-third of the way up again drawing in a fresh charge. The indicator diagram is similar to that of the Lenoir and Hugon engines.

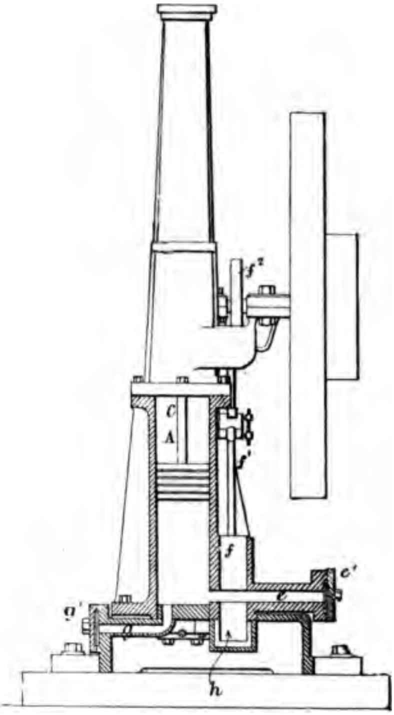

FIG. 25.—BISSCHOP GAS ENGINE (SECTIONAL ELEVATION, END VIEW).

The Bisschop is adapted only for very small powers, one, two and four man-power (half-horse-power), being the usual sizes. Its great merit lies in the simplicity of its parts, and practically no oil is required except for the bearings. In most other gas engines oil is a very large item in the working expenses, hence the Bisschop works more economically than indicated by the gas consumption, which is at the rate of about 130 cubic feet of coal gas per brake horse-power per hour. The two man or $\frac{1}{4}$ horse-power, consumes 30 cubic feet per hour, and the four man or $\frac{1}{2}$ horse-power, 60 to 65 feet per hour.

It does not claim economy of gas when compared with larger modern engines. It occupies small space, requires no water, and its great convenience is to replace manual labour where simplicity and ease in handling are wanted. Hence it is suitable for small industries, and having been found reliable in action is extensively in use.

Messrs. J. E. H. Andrew and Co., Limited, of Stockport, have never ceased to manufacture the "Bisschop" engine since 1878. They are making it at the present day. Surely this is a case of the survival of the fittest!

Proposals for Compression Engine.—The idea of compressing the charge of gas and air in a gas-engine cylinder before ignition, suggested by Lebon, and applied by Barnett, was again revived in 1861. In that year GUSTAV SCHMIDT, in a paper * on the "Theory of the Lenoir Gas Motor," before the Institution of German Engineers, pointed out that the real cause of uneconomical working was want of compression of the cold gases before combustion. He said more favourable results would be obtained, and greater expansion with better transformation of the heat of combustion into work would be possible, if the cold gas and air were compressed to three atmospheres before entering the motor cylinder. MILLION, in his patent, No. 1840 of 1861, also points out the advantages of compression in securing sudden ignition of the gases in the motor cylinder, and the high pressure at which the work is done enables the engine to exert great power in proportion to its dimensions. Like Lebon and Barnett, by means of separate pumps he compresses the gas and air into a reservoir. He proposes to make the motor cylinder longer than necessary, in order that the piston should leave between it and the end of the cylinder a space called a *cartridge*, into which the compressed gases are allowed to enter suddenly from the compression reservoir near the end of the stroke. *Ignition* by the electric spark takes place *at the dead point*, and the whole stroke of the motor piston is utilised for power by the expansion of the gases.

Beau de Rochas.—On the 7th January, 1862, a French engineer, BEAU DE ROCHAS, took out a patent in France, and published a pamphlet in Paris the same year, in which he laid down for the first time on a sound scientific basis the *four chief conditions necessary to obtain greatest economy* and the best results from the elastic force of gases in the gas engine :—

1. The greatest volume of cylinder with least bounding surface.

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* See *Zeitschrift des Vereines deutscher Ingénieure*, 1861, p. 217.

2. Piston speed as high as possible.

3. The longest range of expansion of the gases.

4. The highest possible pressure of the charge before ignition.

Experience, with modern gas engines constructed on these lines, has abundantly proved the importance of these conditions.

1. Beau de Rochas found that in cylinders the loss of heat from gases diminishes rapidly as the diameter increases, and a single cylinder of largest diameter will utilise most heat. The *first rule in gas-engine design* is to reduce all cooling surfaces in contact with hot gases to a minimum. For combustion chamber and clearance space, the ratio of surface to volume should be a minimum, that is, these spaces should be made as nearly spherical in shape as possible. The volume increases as the cube, and the surface as the square of the dimensions, so that the ratio of cooling surface in contact with the gases to the volume occupied by them is less the larger the engine. This is one reason why the rate of consumption of gas per horse-power is less in large gas engines than in small ones. The loss due to friction of mechanism is also less in proportion for large engines at full load than in small ones.

2 and 3. Loss of heat by cooling varies directly as the time. Other things being equal, the cooling will be greater the slower the speed. Moreover, the higher the speed of piston, with prolonged range of expansion within practical working limits, the more rapid and complete will be the conversion of the heat energy into work by the elastic force of the gas.

4. Theoretically, the maximum effect is obtained by compressing the cold gases indefinitely before ignition. Practically, the limit is attained when the temperature due to compression produces premature combustion. As the temperature of the charge on admission into the cylinder is nearly constant, it is possible to determine, for a given mixture, the limit of compression at which combustion is produced, and to design the engine accordingly.

In any case compression, by helping to mix the charge thoroughly, bringing the particles of combustible gas intimately into contact, and by raising the temperature, is favourable to rapid combustion. Weak or dilute gaseous mixtures can be made explosive and easily fired by compression; and a greater quantity of charge may be compressed into smaller space, so that a given size of engine cylinder will develop more power as the compression is increased before ignition. The advantages of high compression and speed are limited by difficulties of mechanical construction, as well as by consideration of the questions of economy, durability, cost and repairs of the engine.

Four-stroke Cycle.—At the same time Beau de Rochas carefully described the cycle of operations that must take place in a single motor cylinder to realise these results, and utilise most completely the heat of combustion of the gases. In one end of his gas-engine cylinder, the series of operations during one cycle of four consecutive strokes of the piston must take place in the following order:—

1. *Suction* or drawing in the charge of gas and air, during one whole outward stroke of the piston.
2. *Compression* of the explosive mixture during the return stroke.
3. *Ignition* at the dead point, and *expansion* during the next forward stroke.
4. *Exhaust* or discharge of the products of combustion from the cylinder during the fourth and last return stroke.

These *four operations* are repeated in the same order, and form the *four-stroke cycle of Beau de Rochas.*

Fourteen years later, in 1876, this cycle was adopted, and made a practical success by Dr. Otto in the Otto "silent" gas engine, and is now chiefly used in gas motors. Beau de Rochas was in advance of his time, and no motor was constructed. He even allowed his patent to lapse, but a pension of 500 francs was awarded him by the "Société des Amis des Sciences," in recognition of his valuable labours to advance the knowledge of the gas engine. Beau de Rochas died in 1892.

CHAPTER [illegible]

CONSTANT-PRESSURE AND REGENERATIVE GAS ENGINES

Brayton.—A gas engine with gradual *combustion* of the compressed mixture of gas and air at *constant pressure* was designed by GEORGE B. BRAYTON of Boston, Massachusetts. Brayton took out a patent in the United States on 2nd April, 1872, after having experimented with his engine at work for many months. In [illegible] a Brayton gas engine was tested by Professor Thurston of the Stevens Institute of Technology. It was designed on a most important principle. There is no sudden explosion, properly so-called. The lighting gas or other carburetted hydrogen—as, for instance, the volatile constituents of petroleum oils—are thoroughly mixed with air in the proper proportion by a pump which compresses the mixture into a reservoir. Two pumps may be employed to compress the gas and air separately into two reservoirs. A gas jet is kept constantly burning in the admission port of the working cylinder. At the commencement of the out stroke of the piston, the valve opens and allows some of the compressed gaseous mixture to pass through several layers of wire gauze (called an "interceptor") which, as in the safety lamp, prevents the flame striking back into the reservoir, but **ignites the gas without rise in pressure as it enters the cylinder.**

Professor Thurston says: "The mixed gases burn steadily as they flow into the cylinder, and the pressure from the commencement of the stroke to the point of cut-off, as shown by the indicator diagrams, is as uniform as that observed in any steam-engine cylinder. The maximum pressure exerted during the trial was about 75 lb. per square inch at the beginning of the stroke, gradually diminishing to 66 lb. per square inch at the point of cut-off, where the speed of the piston was nearly at a maximum, and then declining in accordance with the law governing the expansion of gases."

In the return stroke the piston drives out the products of combustion ; the energy stored up in the fly-wheel carries the engine through the pumping strokes. The engine is single-acting, and there is an impulse every revolution. The action of the engine was smooth and silent, and the flame in the cylinder was under control like steam. But it was found in practice that the weak point was the "interceptor." After a time the meshes of the gauze got burned out or injured in cleaning, and the flame was apt to strike back through the holes and explode all the compressed gaseous mixture in the compression reservoir. The constant flame would be blown out and the engine stopped. These ignition troubles and the lower cost of petroleum led Brayton to use the latter instead of lighting gas. He took out another patent in 1874, and his Ready Motor was one of the pioneer engines using ordinary heavy kerosene.

The Brayton gas engine, tested by Professor Thurston in 1873, was rated at 5 horse-power, and developed on the brake 3·986 horse-power, or say, 4 H.P., and the total power indicated in the working cylinder 8·62 H.P. The amount of gas consumed averaged 32·06 cubic feet per gross indicated horse-power per hour, that is $8·62 \times 32·06$, or a total of 276 cubic feet per hour. Thus the consumption of coal gas was at the rate of $\frac{276}{4} = 69$ cubic feet per brake horse-power per hour. Professor Thurston points out that "the excess of indicated over dynamometric horse-power is to be attributed to the work of driving the compression pump and to the friction of the engine."

Simon's Eclipse Engine.—Messrs. Simon and Son, of Nottingham, introduced the Brayton petroleum engine into England, and brought out a modified form of it—the Simon "Eclipse" Gas and Steam Engine. They exhibited both engines at Paris in 1878. In the Eclipse Engine Messrs. Simon use gradual combustion at constant pressure, not exceeding 50 lb. per square inch, and adopt the plan of passing steam into the motor cylinder for the double purpose of helping to drive the piston by its expansion and at the same time to act as a lubricator by keeping the cylinder moist. However, the novel idea lies in utilising the surplus heat, otherwise lost through the walls of the cylinder, as well as by the exhaust products, to generate steam for this purpose.

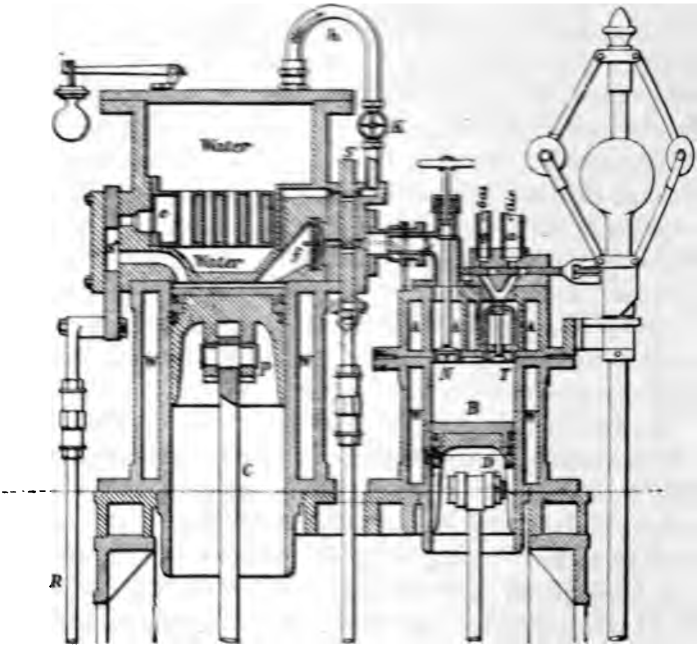


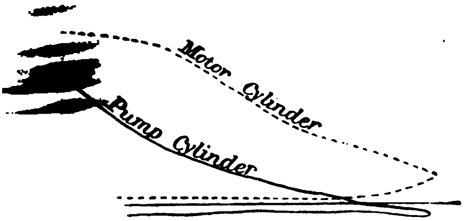
FIG. 26.—SIMON VERTICAL ECLIPSE ENGINE, 1878.

The Eclipse engine is single-acting and vertical.

Fig. 26 is a sectional elevation; the fly-wheel and driving-shaft are not shown, but the cranks are set at ½ centres on the main shaft.

The air-pump piston D, in its down stroke, draws th indicated horse-power, whilst the brake, 4·2 nakes the mechanical efficiency of $\frac{4\cdot 2}{5\cdot 6} = 0\cdot 75$. ımption is 50 cubic feet per brake horse-power

r test of three hours, a 2 horse-power engine r cylinder 8 inches in diameter and a piston feet per minute, gave a mean pressure of uare inch. The air pump was 6·5 inches in e mean pressure 21·1 lb. per square inch. power spent in the air pump, the effective s 4·64 H.P. The brake was 3·5 H.P., and f gas 96 cubic feet per hour, or at the rate oer brake H.P. per hour.



DIAGRAMS FROM SIMON ECLIPSE
·:AS ENGINE.

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Fig. 28 shows the indicator diagrams from this engine when making 146 revolutions per minute. The motor cylinder, diameter 9·25 inches, length of stroke 15·75 inches, and the mean effective pressure by diagram is 22 lb. per square inch indicating 7·7 horse-power.

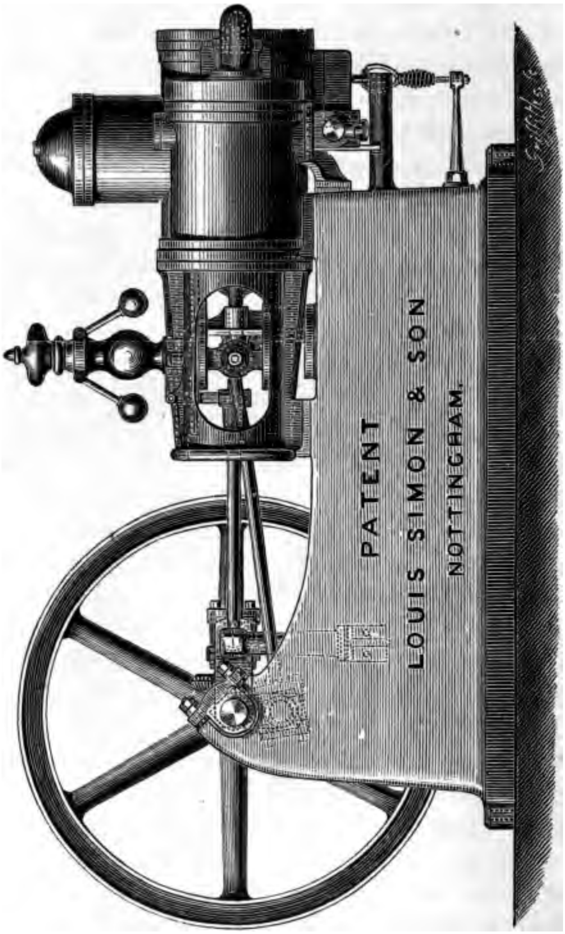

FIG. 27.—SIMON ECLIPSE GAS ENGINE.

The pump cylinder diameter is 7·2 inches, length of stroke 9·84 inches, and mean pressure 16 lb. per square inch; indicating 2·1 horse-power. The difference 7·7–2·1, or 5·6 is the effective indicated horse-power, whilst the brake, 4·2 horse-power, makes the mechanical efficiency of $\frac{4\cdot2}{5\cdot6} = 0\cdot75$. The gas consumption is 50 cubic feet per brake horse-power per hour.

In another test of three hours, a 2 horse-power engine having a motor cylinder 8 inches in diameter and a piston speed of 294 feet per minute, gave a mean pressure of 28·25 lb. per square inch. The air pump was 6·5 inches in diameter, and the mean pressure 21·1 lb. per square inch. Subtracting the power spent in the air pump, the effective indicated power was 4·64 H.P. The brake was 3·5 H.P., and the consumption of gas 96 cubic feet per hour, or at the rate of 28 cubic feet per brake H.P. per hour.

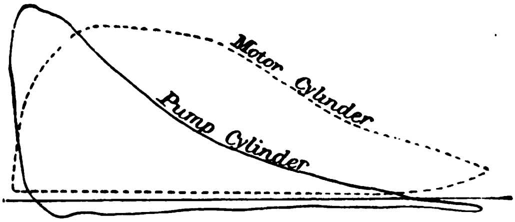

FIG. 28.—INDICATOR DIAGRAMS FROM SIMON ECLIPSE GAS ENGINE.

This design is not at all suitable for engines of small power. The ignition gave trouble. It was often difficult to get the initial combustion or to start the engine, even when the incandescent platinum wire burner or cage was introduced. Heat must also have been lost during the exhaust stroke, as the internal gas jet was kept constantly burning under pressure. The use of steam, although at first sight an advantage, not only produced great cooling effect in the motor cylinder, but also made the engine complicated, so that it became too costly to build and too difficult and expensive to keep in working order. The manufacture was therefore not continued after 1880.

This engine was replaced by an ordinary compression engine, the "Trent" (page 200), of more compact and less complicated construction, the pump and motor pistons being changed into one double-headed piston which performed the same functions. The Trent was brought out in 1890, and its manufacture ceased in 1895.

Siemens' Regenerative Engines.—So early as 1860 SIR WILLIAM SIEMENS had elaborately* worked at the idea of *adapting the regenerator to the internal combustion engine.* The regenerator was invented in 1827 by DR. ROBERT STIRLING, a Scotch minister.

In the Siemens hot-cylinder engine, water gas and air are pumped into a reservoir under high pressure, from thence by a rotary distributing valve through a regenerator formed of layers of metallic gauze, where they are mixed and highly heated before passing into four working cylinders. The front of each working cylinder is connected to and charges the back of the next through a regenerator. The compressed mixture is ignited as it enters each working cylinder, and the combustion is gradual without rise of pressure. The burning gases expand at constant pressure, driving forward each working piston through half its stroke, and the second half is effected by the adiabatic expansion of the burnt gases to double their volume. The products of combustion, after having thus served to propel the working piston by their expansion, are discharged through a regenerator, giving up a large portion of their heat, which is available for heating the next fresh charge of incoming gases passing through the regenerator before combustion takes place in the next cylinder.

In the gas *producer*, steam and heated air under pressure are passed through incandescent fuel, forming water gas—a mixture of hydrogen, carbonic oxide, carbonic acid and nitrogen—used to supply the engine. A gas holder would be required.

A continuous flow of water is kept up round the cylinders.

The working pistons are attached by hollow piston rods to an oscillating disk, at points 90 degrees apart from each other, so that the reciprocating motion they give to the disk is converted into rotary motion of the main shaft carrying a heavy fly-wheel.

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* Patents, No. 12,531, 20th March, 1849; No. 2074, 28th August, 1860; No. 2143, 28th July, 1862. See also the patents 12,006 (1846), 12,531 (1849), 326 (1852), 1363 (1856), 2246 (1873), 2504 and 5350 (1881).

In 1862 SIEMENS patented an improved form of his early engine. As before, the combustible gases and air are compressed and forced by means of a pump into a strong receiver or reservoir, in such proportions as to make a combustible mixture. The pressure maintained in the reservoir should exceed the working pressure to be attained in the combustion chamber connected with the working cylinder.

Combustible petroleum vapour or cheap producer gas may be used. A small quantity of the explosive gaseous mixture is first allowed into a passage, formed in refractory material, where the gases are united and continue to burn, and whence the flame issues into the combustion chamber, firing greater volumes of the mixture. He lines with refractory materials that portion of the chamber in which the gases burn, and the working cylinders where the heated products enter, as well as protecting those parts of the working pistons which come into contact with the flames.

The whole of the products of combustion, after having served to propel the working pistons, are discharged into the atmosphere through a regenerator chamber filled with metal or other good conductor of heat presenting a *large surface for the absorption of the heat* from the gases. The combustible gases and air required to effect the next working stroke are passed in the opposite direction through the same regenerator, in order that they may take up the heat there deposited before they are ignited. Sometimes water is admitted with the gases into the pumping cylinder, to cool and lubricate it as well as to form vapour of water, which it is stated enhances the effect of the gases in combustion.

The valves, pumps and other working cylinders of the engine are surrounded with water-jackets to keep them cool.

In 1862 Siemens exhibited a model engine with two working pistons attached to cranks at 180°, and was *awarded a medal.** None of Siemens' engines have ever come into practical use, nor have any of the actual results obtained from his trials of them been laid before the public, although several large engines of this type have been built. He states that this engine promised to give very good results, but about that time he turned his attention to and spent his life-work mainly in adapting the regenerator to the furnace and metallurgical processes.

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* *The Practical Mechanics' Journal*, Sept. 1862.

Siemens Regenerative Engine.—In the latest regenerative engine designed by SIR WILLIAM SIEMENS in 1881, with *combustion at constant pressure*, we find a *regenerator* or economiser of heat, a *differential piston*, and a simple but *certain mode of ignition* for gases of low inflammability by the electric spark.

Fig. 29 a front and Fig. 30 an end elevation, both partly in section, give a good idea of this vertical engine, which comprises two motor pistons, connected by rods A to the cranks K set 180° apart on the driving shaft which carries the flywheel F.

The trunk piston P is differential, with two heads or ends of different diameter. The lower and smaller end acts as pump, and the upper motor end is the larger. The upper face of each piston is lined with plumbago or fireclay to protect it from the heat. The lower part of each cylinder is surrounded by a cooling water-jacket W, whilst the upper part B is lined with fireclay or other refractory material.

The combustible mixture of gas and air is compressed, through cock H, into the reservoir D.

Admission, distribution and exhaust are effected by a *hollow cylindrical valve* G, revolving between the two cylinders, and driven from the crank shaft by equal bevel wheels *b*. Gas and air are admitted by the pipes *g* and *a* into the annular ports p^1 at the bottom of the valve, and by p^3 at the top, with each cylinder alternately; the port p^2, also at the top, communicates with the exhaust E by the rotary movement of the valve.

Before entering the cylinder above the piston the charge passes through the regenerator, which consists of screens of metallic gauze.

Ignition is by a dynamo on the crank shaft giving the ectric spark at *p*, Fig. 30, within the cylinder B, in a very nflammable mixture obtained by a few drops of petroleum

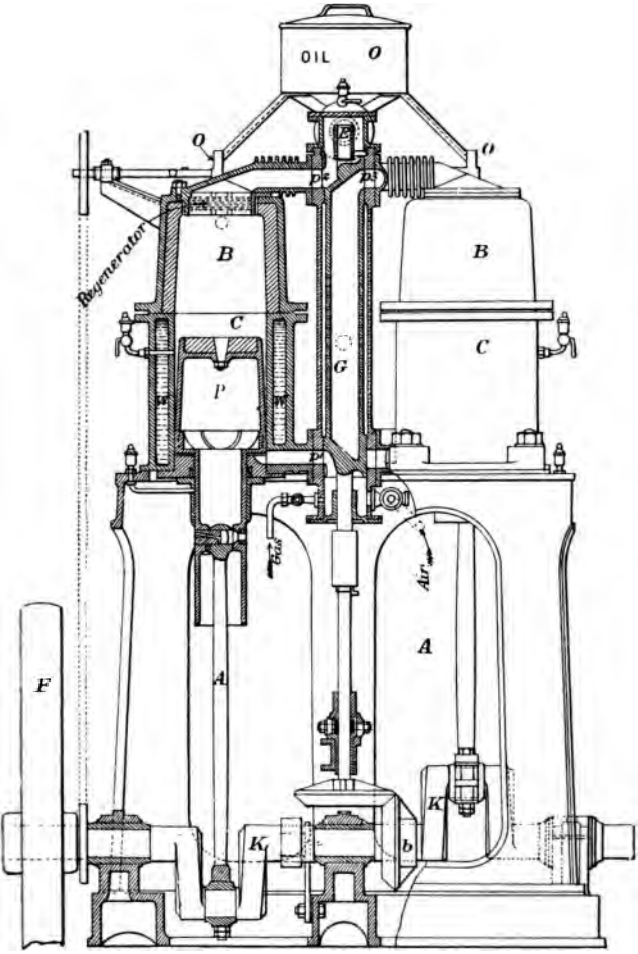

FIG. 29.—SIEMENS REGENERATIVE ENGINE (FRONT ELEVATION).

r volatile hydrocarbon oil carried from the vessel O by the ipes *o*, and deposited by revolving hollow plugs on the first ortion of the charge as it is heated in passing through the egenerator.

The *cycle of operations* in each cylinder is as follows :—

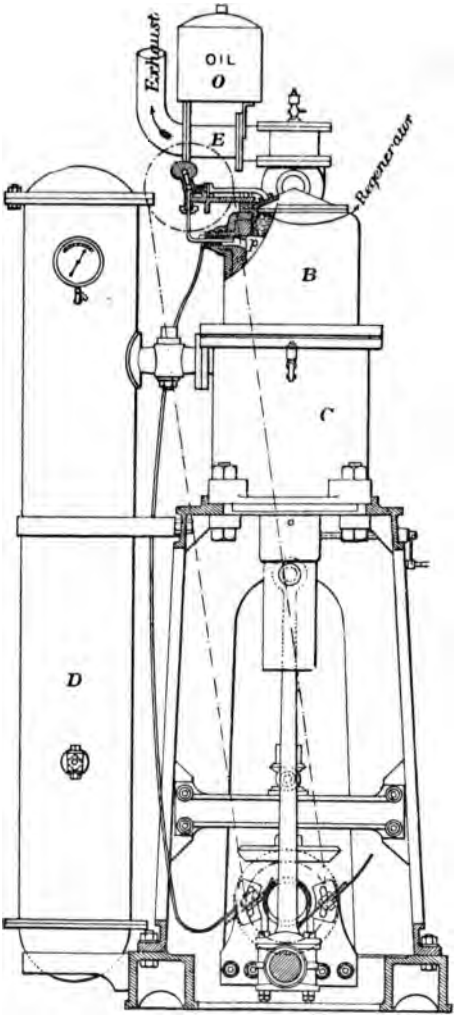

FIG. 30.—SIEMENS REGENERATIVE ENGINE (END ELEVATION).

Starting with the piston P in its lowest position, as shown in Fig. 29, the burnt products of the previous charge in B are free to escape, through the regenerator R and the passage p^2, to the exhaust E.

During the up stroke the lower and smaller end of the piston P draws into the annular space between it and the cylinder the combustible mixture of gas and air through g and a, at the same time that it drives out by its upper face the burnt products through the regenerator R, to which they give up a large portion of their heat before escaping by the exhaust E.

At the end of the up stroke the revolving valve G establishes communication between the reservoir D and regenerator. A portion of the compressed charge, enriched by the petroleum oil from O, and heated by the regenerator, is ignited within the cylinder by the electric spark, and ignites the rest of the charge as it enters the cylinder.

The burning gases expand greatly; but the pressure remains the same as that in the reservoir D, and acting on the full upper area of the piston, drives it down. When the piston has performed part of its down stroke, the supply of gaseous mixture is cut off by the valve G, and the contents of the cylinder at B expand at the expense of their own heat, propelling the piston.

But at the same time, during the down stroke, the lower and annular face of the piston acts as a pump on the mixture drawn in during the up stroke, compressing and forcing it through the opening in the revolving valve G into the compression reservoir D. The piston is thus driven down by a force proportional to the difference of the pressure on its two faces. On the completion of the down stroke the exhaust passage is again opened by the valve, and the expanded products of combustion in B escape through the regenerator, which stores up most of their heat, and restores it to the next incoming charge. Each piston receives an impulse every revolution.

A plan is also given of an engine having four cylinders working on one shaft, each pair working at right angles on a crank opposite to that worked by the other pair. This avoids dead centres. The constant-pressure gas engine promises to give good results, and indicates the latest ideas of Sir William Siemens, who considered that in the application of the regenerator to the internal-combustion engine lies the future development and success of gas engines for very large powers.

Foulis Engine.—FOULIS, of Glasgow, also tried hard to make engines of this type workable. He proportioned the dimensions of the pump and motor cylinders, as well as the strokes of their pistons, so that combustion takes place in the motor cylinder at about the same pressure as that in the pump.

In 1878 he patented a gas or hydrocarbon engine.

Fig. 31 shows a plan, Figs. 32 and 33 combustion chamber, ports and regenerator of the improved horizontal engine, brought out by Foulis in 1881. The combustion chamber

A of the large cylinder is lined with refractory material and kept red-hot. Here the compressed gaseous mixture is burned at constant pressure. The working cylinder C is surrounded by a cold water-jacket. The motor piston is faced with non-conducting materials. The pump B is driven from the main shaft K by crank pin *k*, to which the pump rod is attached, and which is set behind the engine crank at an angle depending on the difference in capacity of the pump and working cylinder, so that the compressed charge burns in the working cylinder under the same pressure as that in the pump. This pump forces the compressed mixture of gas and air by the pipe *g*, inlet valve L, through the wire gauze R, Fig. 33, into the annular space D lined with refractory material, which is kept at a red heat to ignite the gas as it enters the combustion chamber A. The annular orifice D is varied at will by a screw and plunger *p*, as well as the regulator acting directly on the admission valve to control the strength of the charge.

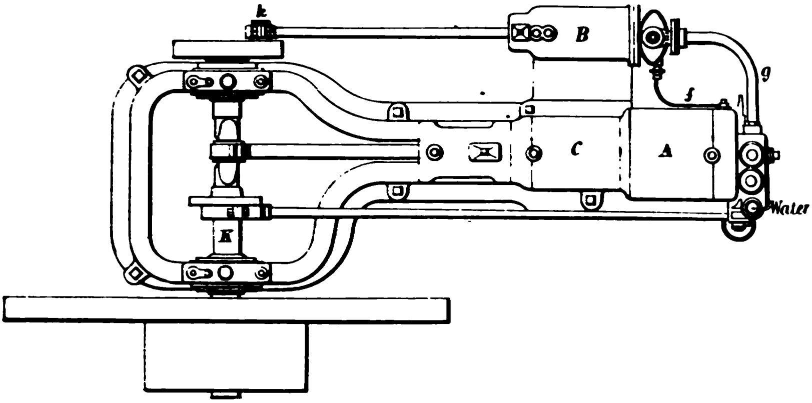

FIG. 31.—FOULIS REGENERATIVE GAS ENGINE.

By a small pipe *f* gas and air pass to the inlet chamber D, Fig. 33, to ignite the mixture; but when the cylinder is heated this is done by the knob *n* of fireclay, or platinum tube, inside the cylinder A, Fig. 32.

The chamber which contains the regenerator R is surrounded with a water-jacket W to prevent the wire gauze being destroyed by the gases at too high temperatures.

The action of the engine is as follows :—

The explosive mixture is compressed and forced by the pump B through the layers of wire gauze R and the annular orifice D into the red-hot combustion chamber A. Combustion takes place gradually at constant pressure only during one-third of the working stroke. After this the admission is stopped and the gases expand, driving on the working piston to the end of its stroke. On the return stroke the exhaust valve E is opened, until near the end of the stroke, when a portion of the burnt products is compressed, but overcome by the pump B forcing the fresh charge through the inlet valve L.

Before being allowed to escape, the products of combustion circulate round the fireclay tubes *t*, Fig. 33, through which the fresh charge passes immediately afterwards from the pump into the hot combustion chamber A. In this regenerator part of the heat usually carried away and lost by the exhaust gases is utilised, being passed through the tubes to the incoming charge before combustion takes place. By burning the gas in a red-hot chamber A lined with refractory material, conduction of heat through the walls of the cylinder may be reduced.

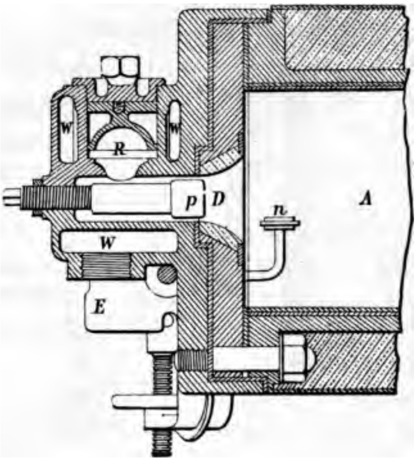

FIG. 32.
FOULIS COMBUSTION CHAMBER.

However, many difficulties arise with gas engines in actual practice which are not apparent when considering the designs on paper, and which have hitherto prevented the realisation of the good results to be expected from such an engine. The construction of this engine was also given up.

Chatterton Engine.—Many proposals and attempts have been made to utilise the heat lost through the cylinder walls to the water jacket. This loss often amounts to half the total heat of combustion of the gases. Experiments have been made with water spray and with steam introduced into the motor cylinder to take up the heat rapidly from the hot cylinder walls, and by evaporation and expansion to give a steam stroke in which some work would be developed from the heat usually carried away by the cooling water.

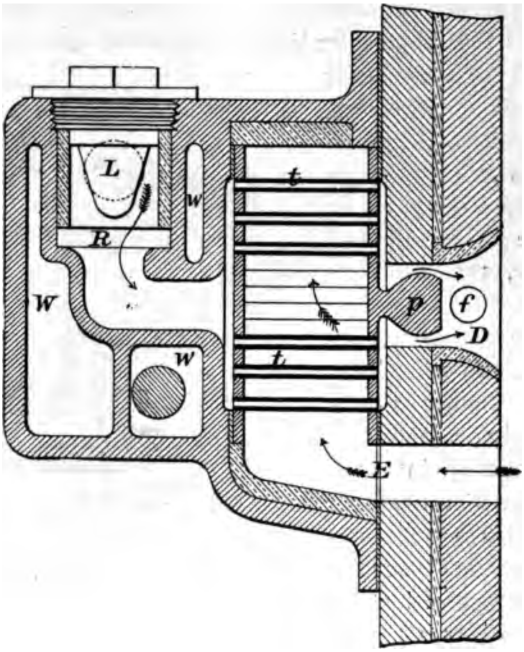

FIG. 33.—FOULIS ENGINE (GAS PORTS AND REGENERATOR).

In 1892 BERTRAM CHATTERTON designed, for engines above 30 horse-power, a combination of a gas engine and steam engine, having a gas stroke and steam stroke alternately in the same cylinder without jacket. The waste of heat to the cylinder walls, due to the high temperature of the gas explosion, is absorbed by the incoming steam of the next stroke, thus preventing initial condensation. In starting, the steam alone is used every stroke until the proper speed is got up.

The engine is vertical, like a marine engine. The cylinder is single-acting and mounted on a strong cast-iron standard at the back, and supported in front by steel columns. The trunk piston is directly joined to the connecting rod. The explosive mixture is compressed in an air pump and discharged into a high-pressure reservoir to supply the cylinder every alternate stroke with compressed gas, which is admitted for part of the stroke and then cut off and exploded electrically. The steam and gas are kept distinctly separate in an outside chest from which, by an ingenious mushroom valve with balance piston, they are admitted alternately to the working cylinder through the same port. The power is varied by regulating the cut-off for both steam and gas. A condenser was not used for the steam on account of the air entrapped in the clearance space, about 2 per cent. of the volume displaced by the piston.

Chatterton tried various forms of ignition apparatus, and finally found that the most reliable was by a continued succession of electric sparks in a little box covered by a valve which was opened quickly.

The cylinder was kept at a uniform temperature by priming water in the steam, which took up the heat from the hot cylinder walls and thus utilised the ordinary loss. The temperature was observed by mercury in holes bored vertically in the sides of the cylinder. It was maintained at about 375° F. for a run of five or six hours, and did not become hotter.

The indicator diagrams, Fig. 34, for the two strokes, show the admission and expansion of the steam (thick line), also the admission and ignition of the compressed explosive mixture (thin line). The dotted lines show retarded explosions. The expansion of gas was to about two-and-a-half times the original volume of the mixture before compression. The gas was compressed to about 20 lb. per square inch; and the boiler pressure was 90 lb. per square inch. The mean pressure from the diagrams was, during the gas stroke, 28·4 lb. per square inch, and for the steam 30·4 lb. per square inch. The engine worked best at a speed of 120 revolutions per minute.

The best results were about 14 lb. of steam and 11 cubic feet of coal gas used conjointly per indicated horse-power per hour, and about 18 lb. of steam and 14 cubic feet of London coal gas conjointly for each brake horse-power hour.

One of the greatest defects was the shock produced by the extremely violent explosion. This was doubtless due to the presence of steam in the cylinder, which made the time of ignition of the gases unreliable and beyond control. After working at this engine for nearly three years Chatterton abandoned it.

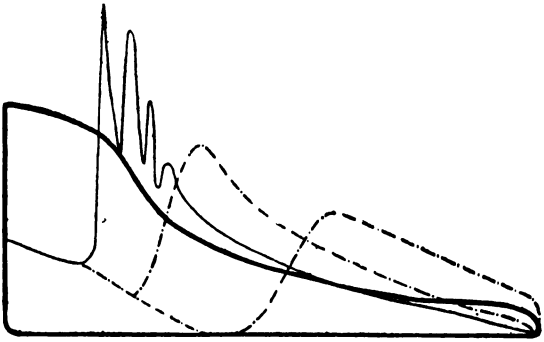

FIG. 34.—INDICATOR DIAGRAMS. STEAM AND GAS ENGINE.

In common with Sir William Siemens, he considered that the constant-pressure gas engine would be likely to show good results in the future. The difficulty of introducing the charge into the cylinder could be overcome, as in his alternate steam and gas engine, by having separate pumps for the gas and air. By isothermal compression to 150 lb. per square inch the charge might be introduced into the cylinder, and by electric ignition burned at constant pressure. Then, after cut-off, the expansion could be carried beyond the original volume if desired. Here the regenerator could also be used.

CHAPTER V.

OTTO GAS ENGINE.

THE year 1876 marked a fresh era in the history of the gas engine, and an important stage in its development, for then the invention of the Otto Silent engine was quite a new departure in the application of gas as a source of motive power. The excitement of 1860 had attracted public attention and led many inventors into the field. Still the gas engine was not popular. The Lenoir and Hugon engines were too expensive in gas consumption. The objectionable features in the design and noisy action of the free piston engine of Otto and Langen induced these inventors to take up the principle of direct action with compression. It was observed that the rapidity of burning, or the rate at which the pressure was developed by the combustion of an explosive gaseous mixture in a closed vessel, was lessened by the presence of those inert gases, such as nitrogen, which do not enter into combination with any other gas present.

Experiment showed that by varying the strength of the mixture the *rate of combustion could be varied*, and was thus completely under control. With a weak mixture the combustion took place slowly, while the inert diluting gases absorbed a large quantity of the heat generated.

In the patent No. 2081 applied for in England on the 7th May, 1876, by Nicolaus August Otto, for "gas engines in which the motive agent burns gradually," the German engineer Dr. Otto proposed to arrange an **imaginary stratified mixture**, composed first of a portion of the burnt products from the previous explosion left in the cylinder next the piston. This layer was intended to dilute the incoming charge, and act as a cushion to deaden the shock of the explosion. He introduced pure air during the early part of the admission stroke, and then the combustible mixture of air and gas was admitted, becoming richer in gas until the air port was closed and gas alone entered the cylinder at the end of this stroke.

Stratification is now generally admitted to be only partial; and it is, moreover, inconsistent with the nature of gases to remain in distinct layers or slices when agitated as in the engine cylinder. Experiments with smoke in glass models, of the *same size* as the Otto cylinder, show that the great velocity of the gases rushing into the cylinder projects them against the piston, producing eddies or whirls, whilst the whole contents of the cylinder are mixed by the commotion and crowding together of the gaseous particles on the return of the piston during the compression stroke.

However, the richer mixture near the port or touch-hole made the charge more easily ignited, whilst the dilution of the charge, by the residual products, undoubtedly led to gradual and prolonged combustion, or after-burning, throughout the explosion stroke.

Now, it is found that in the engine cylinder the temperature of the gaseous mixture is raised by *compression* before ignition, whilst a smaller surface is exposed for cooling per unit weight of gas. At the same time, compression makes the poor mixture more readily inflammable, and increases the rate of propagation of the flame throughout the entire mass. Moreover, the change of pressure by the explosion will not be so sudden as to cause serious wear and tear in the mechanism, which is prepared to receive the shock.

The Otto Silent, as distinguished from the noisy free-piston engine, was designed to embody all these points, and worked on precisely the same cycle of operations as proposed by Beau de Rochas fourteen years previously (see page 79). In contrast the latter would ignite the charge by compression alone, and desired instantaneous explosion with rapid expansion. Otto ignited by flame shot into the charge, and instead of explosion he sought to obtain slow combustion from particle to particle, giving gradual development of heat and expansion of the gases. The economy of gas or gain of efficiency in this engine is mainly due to compression of the charge before ignition, and to the four-stroke cycle of operations, although Dr. Otto attributed his success to the stratification of the charge. Anyhow, to Dr. Otto belongs the credit of having made the first compression gas engine which proved a practical working success and came into general use, and the Otto four-stroke cycle has been almost universally adopted, with modifications, by the leading makers of modern gas engines.

This most common type of internal combustion engine, known as the **Otto Silent gas engine**, was shown at the Paris Exhibition of 1878.

The engine is horizontal, with the cylinder open at the end next the crank-shaft. The piston cross-head slides between guides made to fit it accurately. The piston is long, of trunk type, and as light as possible consistent with safety. The piston slide is directly attached to the crank by the connecting rod. When the piston is as far as it will go into the cylinder at the end of its stroke, there is a clearance space behind it in the back of the cylinder equal to about two-thirds of the cylinder volume swept by the piston. This serves as the compression space or *cartridge.* All the operations take place at the back end of the cylinder and on the one side of the piston only. The cylinder is surrounded by a water-jacket through which water circulates to keep the inner surface cool, so that mineral oil can lubricate the piston. A counter-shaft or lay-shaft, parallel to the cylinder and driven by bevel gearing at half the speed of the crank-shaft, performs several functions: (1) by means of a crank it moves the slide valve backwards and forwards across the back end of the cylinder for the admission, distribution and ignition of the charge; (2) it drives the centrifugal governor to throttle or cut off and control the gas supply to regulate the speed of the engine; (3) the exhaust valve is lifted by a lever operated by a cam on this counter-shaft; and (4) a strap from it drives the lubricator to supply oil to the cylinder and slide valve. The

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whole cycle of four piston strokes is carried out in the one cylinder and by the one piston during two revolutions of the crank-shaft.

We can easily follow these operations on an actual **indicator diagram**, Fig. 35, taken from an Otto engine. It will give us at once an idea of the alterations in pressure and volume of the gases in the cylinder during one cycle at full load.

The arrows indicate the direction of the piston's motion. Horizontal distances, measured from 1, represent, to a given scale, the distances in feet travelled through by the piston. Thus the line 1, 2 corresponds to the length of travel of piston. The clearance space is about two-thirds of the length 1, 2 to the left when the piston is at the end of its in stroke at 1; so that the whole *volume* of gases behind the piston can be determined for any point of the stroke.

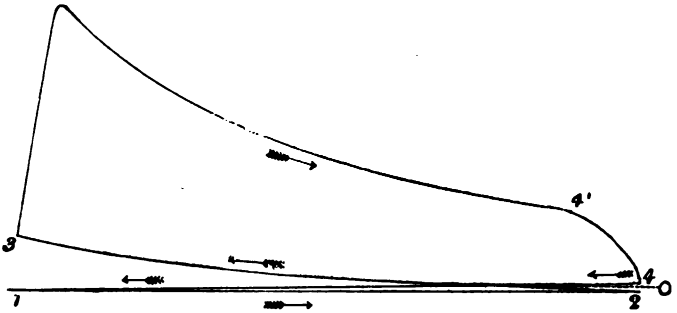

FIG. 35.—INDICATOR DIAGRAM FROM OTTO GAS ENGINE.

Distances measured vertically from the line O, 1 give us the pressure in pounds per square inch, above or below the atmospheric pressure, in the cylinder at any point of the stroke. The line O, 1 is the atmospheric line, and the height above it to any part of the curve represents the pressure, above atmospheric, in the cylinder at that point in the stroke. Thus, **heights represent pressures, and horizontal distances the travel of the piston.**

Now, starting with the piston at the end of its in stroke in position (1), Fig. 35, and the clearance space filled with products of combustion at atmospheric pressure, we shall have the following operations :—

1st Stroke, Suction or Charging.—The forward stroke of the piston from 1 to 2, during which the charge of air and gas is drawn through the slide-valve passages into the cylinder. The line 1, 2 is slightly below 0, 1, showing that the pressure all along is less than atmospheric, owing to the vacancy left by the piston, and the cooling of the cylinder by the jacket water, hence the great indraught of air and gas with throttling in the slide ports. At 2, Fig. 35, the inlet port is closed by the slide, when the piston is at the outer end of its stroke and the pressure of the charge in the cylinder is below that of the atmosphere, due to throttling.

2nd Stroke, Compression.—The line 2, 3 shows the compression of the fresh charge and burnt products during the return stroke of the piston. We see the line 2, 3 gradually rises, until at the end of the stroke the height above 1 represents a pressure between two and three atmospheres, notwithstanding the cooling of cylinder and gases by the jacket water. One revolution of the crank-shaft is now completed. At 3 the crank has just passed the centre, and the piston is commencing its next forward stroke as the charge is fired by a flame in the ignition port of the slide at the back end of the cylinder.

3rd Stroke, Combustion and Expansion.—At 3 we have ignition and explosion or combustion, the pressure rises rapidly, and then falls off gradually as the gases burn and expand by the heat of combustion driving forward the piston and doing useful work. Before the end of stroke, at the point of release 4′, the exhaust valve opens and allows the gases to escape. In this operation the heat of combustion has expanded the gases, raised the pressure, and driven the piston, overcoming the resistance of the mechanism and getting up speed. This is the only part of the cycle in which heat is converted into actual work, hence it is called the *working stroke.*

4th Stroke, Exhaust.—The line 4, 1 shows the pressure in the cylinder during the return stroke while the piston drives the products of combustion out of the cylinder, with the exception of what remains in the clearance space untraversed by the piston, and thus completes a **cycle of operations.**

We are now back at our starting point. The crank-shaft has made two revolutions, and the engine simply goes through the same operations over and over again. The energy that is stored up in the fly-wheel during the explosion and expansion of the charge has to carry the engine through all the rest of the cycle, that is, enables the engine to reject the burnt products, to draw in and compress a fresh charge of air and gas, which is again fired, burned and expelled as before.

There is only one explosion every second revolution when the engine is working at full power. The explosions may take place much more rarely when the engine is running with a light load. Then the gas is cut off by a centrifugal governor which allows more or less gas into the supply pipe, depending upon the speed of the engine. When the speed is too high no gas is admitted, only air is drawn in, compressed, allowed to expand and then discharged by the exhaust, thus cooling the cylinder. It is therefore necessary to have large and heavy fly-wheels and to run at high speed in order to have steady uniform driving.

On account of the demand by the engine for gas being sudden and intermittent, it is usual to have on the main gas pipe, as close to the engine as practicable, a flexible india-rubber bag, to act as a gas reservoir and give regularity to the supply required. This large **anti-fluctuating gas bag** or reservoir is placed between the engine and the gas supply main to prevent the sudden suction of gas by the engine causing pulsations or sudden changes of pressure in the gas main. The back side of the anti-fluctuator bag is a flexible diaphragm of canvas, covered with rubber, to which the rod of a little piston valve is attached. The other side is of cast iron, carrying the gas inlet pipe containing a V-shaped slot which is uncovered by the little piston valve so as to admit gas gradually when the valve is moved from the flexible diaphragm of the gas bag under the action of the engine, thus:—When the bag is filled and the rubber inflated, the cut-off closes the gas inlet. The engine then draws a charge from the bag and flattens the rubber, which moves the piston valve past the slot and allows the bag to be re-charged by the pressure from the gas main. In this way, by drawing from the large gas bag when the supply pipe is shut off from the main, the pressure in the latter is not seriously varied to give unpleasant pulsations of the neighbouring gas lights.

In studying the construction of a machine like the gas engine, the student would do well to examine an actual engine, make drawings of its several parts, and carefully observe its

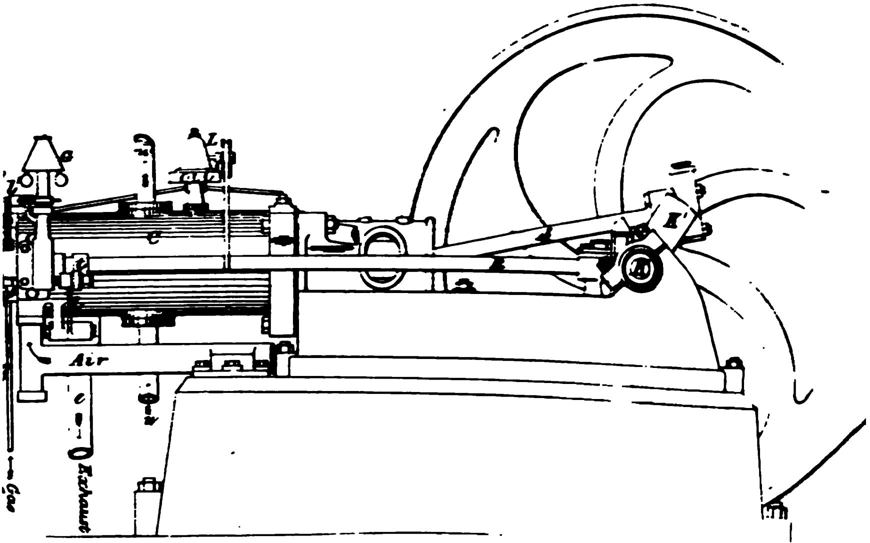

FIG. 36.—EARLY OTTO GAS ENGINE [illegible]

action for himself. The information gained [illegible] amply repay him for the time and care [illegible]

A good idea of the general arrangement [illegible] motor of this type can be gathered from [illegible] or elevation of a nominal 7 horse-power [illegible] a horizontal section of the ordinary [illegible] whose action we have just been considering [illegible] reference letters on the corresponding [illegible]

One fly-wheel is omitte

fusion. There are usually two fly-wheels, one keyed on each end of the crank-shaft K to balance the machine and give more regularity of speed.

The cylinder C is open to the air at the end next the crank-shaft, and the cross-head slide P′ which moves between guides in this open space is attached directly to the crank K′ by the connecting rod A. The slide guide is cast with the bedplate forming part of the engine frame, and must be fitted truly in line and concentric with the cylinder. The cylinder is bolted to the bed against a faced flange. The **water-jacket** W surrounds the cylinder, and the water is kept continually circulating by two pipes leading to a cooling tank at a higher level. The water flows from a tank through one pipe to the bottom of the cylinder, circulates through the jacket to the top of the cylinder, and back again to the top of the tank by the other pipe. When the engine has

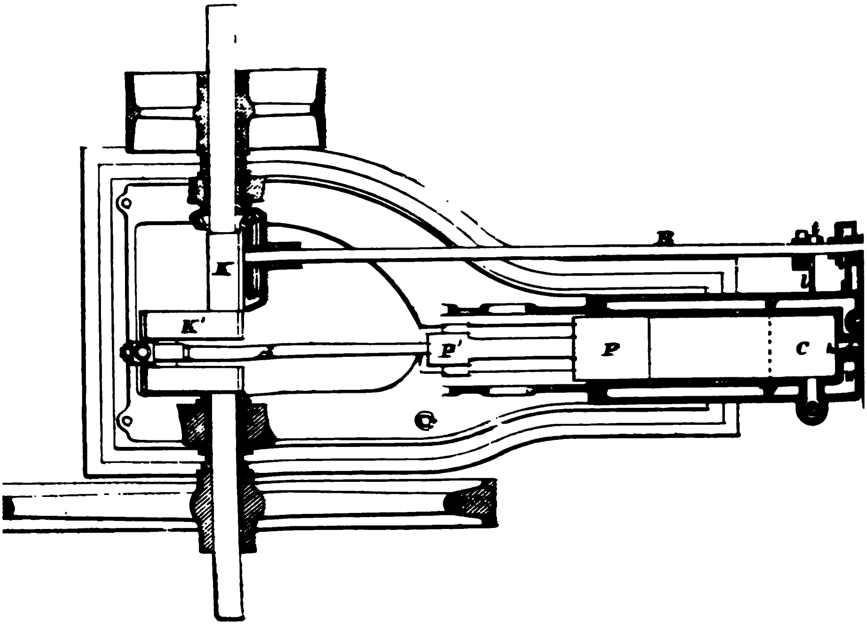

FIG. 37. EARLY OTTO GAS ENGINE (HORIZONTAL SECTION).

been working for some time, the water leaves this jacket at a temperature of about 140° Fahr., or 60° C. The cooling water tank radiates heat, and is made sufficiently large to remain cool during continuous working. Sometimes the water is taken directly from the water mains, but it should be allowed to escape by a pipe from the top of the cylinder, and sloping upwards, in order to prevent syphoning and keep the water jacket always full when the engine is working. In time of frost the jacket should be drained, when the engine is not working at night, to prevent fracture of the cylinder by the water freezing in the jacket.

The **lubricator** L is driven by an endless leather strap off the counter-shaft R, and gives a constant supply of oil to the slide valve S and piston P through two little pipes, as shown in Fig. 36. It is all-important that the lubricator should not be allowed to run dry, else the slide valve S is liable to be burned and injured from want of oil.

The **lay-shaft** R, driven by bevel wheels or **skew gear** from the crank-shaft K, makes one revolution for every two of the fly-wheel. The cam and tappet *t* on this counter-shaft R acts on the lever *l*, opens the exhaust valve, and allows the products of combustion to escape by the pipe *e*.

On the shaft R there is a cam which, as it revolves, knocks up a little bowl or roller and lever, and opens the gas supply valve *g* during the charging stroke, in opposition to a spring which quickly closes the valve as soon as the cam allows it. There are steps on the cam enabling it to vary the supply of gas by pressing up the bowl and lever a longer or shorter period of time. The **centrifugal governor** G, by means of the lever *l′* moves the bowl to and fro upon the shaft, so that this little roller either comes in the way of the cam when the engine is working at proper speed, or escapes the cam so that the supply valve is not opened and there is no admission of gas when the speed is too high. Thus the centrifugal governor balls, as they rise and fall with the speed, completely control the supply of gas.

The side-shaft R also actuates, by crank and arm *t*, the **slide valve** S, which alone ingeniously and effectually serves for the *admission, distribution* and *ignition* of the charge. This slide valve, Fig. 38, works between the face plate on the end of the cylinder and a cover, Fig. 39, which is held against it by two spiral springs F, F, Fig. 36, under two nut screws, keeping the slide in its place close to the back of the cylinder, so as to prevent leakage of gas therefrom.

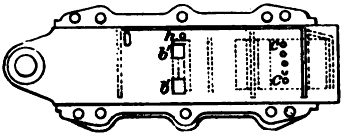

FIG. 38.—OTTO SLIDE VALVE.

The main gas supply pipe *g* and the air passage *a* communicate at the proper time through the slide-valve passage *b* with the port *d*, which leads into the cylinder. A separate gas pipe *f* feeds the two slide lights, the one *f* in the slide cover is continually burning in the open air in the lower part of chimney, shown in figure; the other *f'* is intermittent and re-lighted, after each explosion, by the fixed burner outside.

A groove *g'* is formed in the slide-valve cover, and receives gas by a separate pipe; it is closed by the slide valve except when the lighting port *b'* comes opposite to it, then *b'* is supplied with gas through the groove *g' f'*. The hole *h* in the cylinder face is the equilibrium lighting port, and level with it there is a narrow conduit *h* in the slide, as well as two holes *k*, Figs. 38 and 40. In this way there is free communication between the cylinder and *b'*, a little before it is brought up to *d'*, the position of the slide valve in Fig. 44.

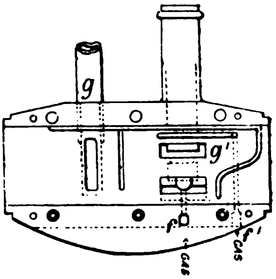

FIG. 39.—SLIDE-VALVE COVER.

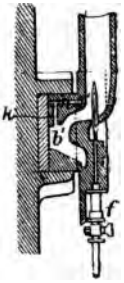

FIG. 40.—LIGHTING CHAMBER.

All these passages and holes in the slide valve should be carefully cleaned at least once every 60 hours' continuous running. The slide valve must also be kept well oiled. In fact, if ignorant or careless attendants neglect the oil supply, or allow dirt to fall on the working surfaces, the slide ignition valve may at any time during a run get burned, cut or scored, and so stop the engine.

In order to get ready for **starting the engine**, see that the driving belt is on the loose pulley, and turn on the water by the tap at the cooling tank, so as to have it circulating in the water-jacket round the cylinder by the pipes *w*, *w*, Fig. 36. Next move the governor G to its middle position, and fix the little tumbler catch underneath which props up the governor balls, so as to bring the little roller opposite the gas cam until the first explosion starts the engine, when it falls back automatically. It is difficult to turn the fly-wheel during the compression part of the stroke, unless the exhaust valve is kept open. For this purpose change the pin which secures the cam *t*, and move the cam along the shaft that it may act on the exhaust-valve lever every half revolution. Move the exhaust-valve lever by hand to let out any gas or air that may have accumulated in the cylinder and passages. Light the external gas jet *f*, and the inner or slide light *f'*. Then fill the gas bag behind the engine, and shut off the main supply of gas. Lastly, open the gas cock on the cylinder, and give the fly-wheel a few sharp turns. When an explosion takes place and the engine starts, turn on the main gas supply and push back the cam *t* to its proper position. If the engine be clean and properly oiled it requires no further attendance, but works safely and steadily, and is stopped by simply turning off the gas. This plan of keeping the exhaust open while starting entails the danger of an explosion in the exhaust pipe.

A small gas engine is sometimes used to start a large one, but more frequently a **self-starter** is employed, which saves the trouble of pulling round the fly-wheel to produce the first explosion and to get up speed. A charge of gas and air is admitted and fired to give the first impulse to the piston in the working stroke.

The Action of the Otto gas engine is as follows :—

Fig. 41 shows the position of the slide valve going in the direction of the arrow at the beginning of the forward charging stroke, when the piston is at the point indicated by the dotted line, Fig 37. As the piston moves forward, air is drawn first from *a* into *b*, where it mixes with gas afterwards admitted from *g* through a series of holes *c c*, Fig. 38, so arranged as to have the mixture of any desired strength, and to let the gas enter a little after the air port is shut.

The idea was to have the charge at the moment of ignition not quite homogeneous : the mixture being rich in gas near the slide-valve port, but poorer and mixed with the residual products near the piston. It is evident, when one considers the great velocity with which the incoming gases enter the cylinder, there must be a nearly homogeneous mixture in the centre of the cylinder after compression and before ignition takes place.

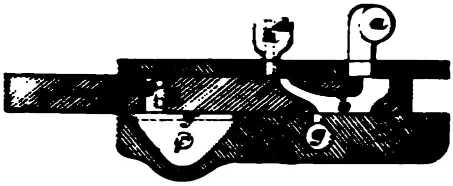

Fig. 41.—Slide Valve for Admission of Charge.

Whilst in the position shown, Fig. 41, the mixture is passing through the other end of the passage *b* into the cylinder by *d*. The lighting port *b'* is receiving gas from the groove *g'*, and this is burning in connection with flame *f* in the chimney. This continues while the line 1, 2 of the **indicator diagram,** Fig. 42, is being traced, until the piston reaches position P, Fig. 37. (The arrows on the diagram indicate the direction of the piston.) The pressure is somewhat less than atmospheric, owing to the vacancy left by the piston and the cooling effect of the jacket water, hence the suction and rapid inrush of air and gas. The narrow ports of the slide valve offer resistance to the incoming charge which is thus partly throttled, so that the full charge in the cylinder at the end of the suction stroke is below atmospheric pressure.

The gas supply should be slightly above atmospheric pressure, and the ports large to admit the gas and air freely. Otherwise the weight of charge is reduced, and therefore the power of the engine. At 2, Fig. 42, the port *d* is closed by the slide valve, and the return stroke of the motor piston compresses the charge into the clearance space or cartridge C, between the dotted line, Fig. 37, and the back end of the cylinder. The line 2, 3 gives the rise of pressure due to compression, to about 30 or 40 lb. per square inch at the point 3, Fig. 42, before ignition.

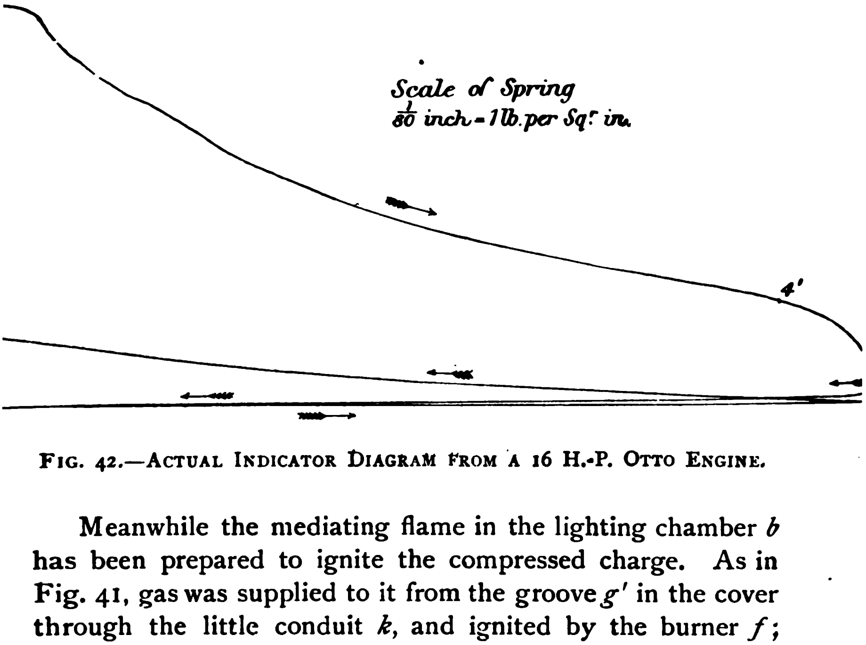

FIG. 42.—ACTUAL INDICATOR DIAGRAM FROM A 16 H.-P. OTTO ENGINE.

Meanwhile the mediating flame in the lighting chamber *b* has been prepared to ignite the compressed charge. As in Fig. 41, gas was supplied to it from the groove *g'* in the cover through the little conduit *k*, and ignited by the burner *f*; afterwards this is cut off as the chamber *b'* filled with the lighted gas is carried to the right past *g'* and isolated; then, before *b'* is brought opposite to *d*, it is placed in communication with the cylinder C by the little narrow holes *h* and *k*, through which a small portion of the rich compressed charge from the cylinder enters, to strengthen the flame and gradually raise the pressure in *b* up to that in the cylinder C. The burning mixture in *b'* expands, its pressure rises even higher, and when the slide valve arrives in position, Fig. 44, the next forward or working stroke is just beginning, *b'* shoots a tongue of flame through *d* and fires the rich compressed charge near the port, the cylinder being now completely closed by the slide valve. The rich mixture near the end of the cylinder burns first, and the flame spreads through the rest of the charge gradually whilst the piston moves forward. The rate of combustion and consequent increase of pressure is completely under control by the dilution and compression of the mixture, as well as by the way in which this mixture is fired.

The maximum temperature reached is probably about 1600° C.; the pressure rises rapidly, as indicated by the line 3, 4', 4, Fig. 42, whilst the burning gases expand, driving the piston forward during this working stroke.

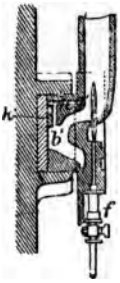

FIG. 43.—LIGHTING CHAMBER.

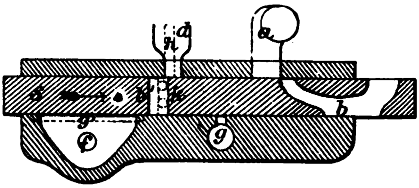

FIG. 44.—FIRING OF CHARGE.

It has been calculated that about half the total heat of combustion of the charge is developed as heat when the maximum pressure is produced in the cylinder, the rest being developed afterwards. The gradual and prolonged combustion should be as complete as possible at about 4', Fig. 42. The tappet *t*, Fig. 36, opens the exhaust valve *e* by the lever *l*, and allows the burnt gases to escape at about 400° C., and the return stroke of the piston expels them at atmospheric pressure, as shown by the line 4, 1. The piston only comes as far as the dotted line, Fig. 37, so that part of the burnt products are left in the clearance space at the end of the cylinder not swept by the piston.

The water-jacket cools the cylinder, whilst a fresh charge of air and gas is *sucked in* and mixed with the residual products, *compressed*, *burned*, and *expelled* as before. Thus we have one explosion every two revolutions, whilst the slide valve moves once forward and back again.

The Otto engine runs at 160 revolutions per minute, and the average speed of piston is from 320 feet per minute in the small sizes up to about 500 feet per minute. At this speed and with heavy fly-wheels the cyclical variation is not considered objectionable for ordinary purposes, especially when the economy in gas consumption is so marked, and the efficiency better than in any previous heat engine.

The Otto came widely into use, and in the first ten years more than 30,000 engines were sold. Messrs. Crossley, of Manchester, began to make the Otto and Langen atmospheric gas engine in 1868, and abandoned it in 1877 in favour of the Otto "silent" engine described above.

Trials.—Many careful trials were made of this engine in its early form, and the results of the more important are given in the table on page 112.

In these tests the compression space is 60 per cent. of the volume swept by the piston. The most complete measurements were made by Messrs. Brooks and Steward under the direction of Professor Robert H. Thurston, at the Stevens Institute of Technology, Hoboken, in America. The ratio of air to gas in the charge which gave best results, was found by direct measurement to be 7 to 1. The temperature of the exhaust gases was observed by a pyrometer to vary from 399° C. to 432° C. at full load. Professor Thurston estimates that at the point of highest pressure on the indicator diagram, that is, of highest temperature in the cylinder, there is only about 60 per cent. of the total heat of combustion generated. Dr. Slaby gives it as 55 per cent. In the latter case the combustion was more gradual, inasmuch as the coal gas at Deutz was not so rich, and the mixture less explosive, being 1 part by volume of gas to about 10 of air, according to Slaby. The temperature of the gases in the exhaust pipe was between the melting points of zinc and antimony, that

RESULTS OF TRIALS OF EARLY OTTO GAS ENGINE.

Test made by	Slaby *	Brooks and Steward †	Adams and Sprague ‡	Adams and Sprague	Adams and Sprague
Place	Deutz.	Hoboken, U.S.	Crystal Palace, London (*a*)	Crystal Palace (*b*)	Crystal Palace (*c*)
Date	August 1881	June 1883	1882	1882	1882
Nominal horse-power	4	6	12	16	2
Diameter of cylinder, inches	6·75	8·5	12	13	5·75
Length of stroke, inches	13·38	14	16	21	12
Revolutions per minute	156·7	158	158·7	151·37	160·3
Mean effective pressure, lb. per sq. in.	52·9	..	62·2	63·08	54·31
Indicated horse-power	5·04	9·6	22·55	33·6	3·43
Brake horse-power	4·4	8·1	18·31	27·75	2·87
Mechanical efficiency, per cent.	87	84	81	82·6	84
Total gas used per hour, cubic feet	142·67 ignition 2·75	235	533·4	841·6	95·8
Gas per brake H.P. per hour, cubic feet	32·4	29·1	29·1	30·3	33·4
Heating value of 1 cubic foot in B.Th.U. (calculated from analysis)	547·3	617·5	633·8	633·8	633·8
Thermal efficiency:—					
Percentage of heat of combustion turned into work in cylinder	16	17	17	16	14·5
Heat lost by jacket water, per cent.	51	52	..	..	..
Heat lost in exhaust gases „ „	31	15·5	..	..	..

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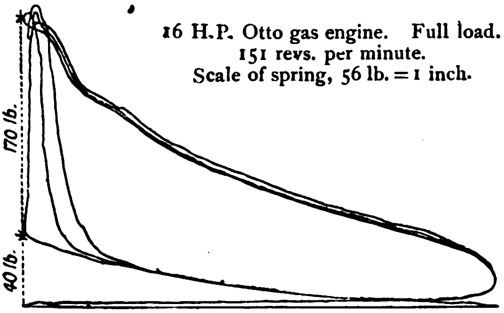
* For further details, see Appendix to lecture by Prof. Fleeming Jenkin on "Gas and Caloric Engines," delivered before the Institution of Civil Engineers, on February 21, 1884.

† 'Van Nostrand's Engineering Magazine,' February 1884.

‡ Inaugural address by Prof. W. Grylls Adams, as President of Society of Telegraph Engineers and Electricians, 1884; also more details in 'State Papers—America—Information from Abroad—Report on the Exhibits at the Crystal Palace Electrical Exhibition, 1882,' by Frank J. Sprague, issued by Naval Department, U.S., Washington, 1883–4.

is, 423° C. and 432° C. The results agree very closely as to the fraction of the total heat energy of the gas turned into actual work indicated in the engine cylinder, viz. 16 and 17 per cent.; whilst fully half of the total heat generated is lost through the cylinder walls and carried away in the cooling water. The total gas consumption, including that used for the igniting flame by Slaby, is 35·15 cubic feet per brake horse-power per hour.

By calculation from analysis of the town gas of Cologne, as used at Deutz, the total heat of combustion is 5372·2 calories per cubic metre, that is 691·7 B.Th.U. per cubic foot. This estimate is based on the assumption that the steam produced by the combustion is condensed. Deducting the latent heat of the steam produced, 54·4 B.Th.U. per cubic foot of gas burned gives the *actual heating power* of the gas 547·3 B.Th.U. per cubic foot, or 4886 calories per cubic metre, taken by Dr. Slaby.



16 H.P. Otto gas engine. Full load.
151 revs. per minute.
Scale of spring, 56 lb. = 1 inch.

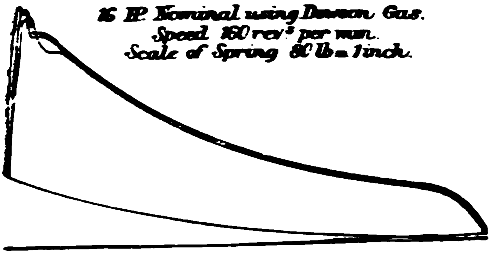
(Half actual size.)

FIG. 45.—INDICATOR DIAGRAMS. PRE-IGNITION BY HOT CYLINDER.

In the experiments by Adams, Sprague and others at the Crystal Palace, London, after running the 16 horse-power engine half an hour, at full load, the cylinder became so hot that no flame was required to ignite the charge. The engine ran at full load five to ten minutes without a flame in the slide valve to fire the gases, and several indicator diagrams, Fig. 45, were taken, showing ignition of the charge by compression in a very hot cylinder. These show premature ignitions giving back-pressure on piston.

In normal working the maximum pressure was increased and the efficiency of the engine greatly improved by higher compression of the gases before ignition. It was also found that from the point of ignition to the time of reaching maximum pressure the interval was between 0·02 and 0·05 of a second.

The greatest amount of work is done when the maximum pressure is reached at the beginning of the working stroke, that is, when the explosion takes place promptly and rapidly, the heat being generated and converted into work done on the piston before there is time for cooling the cylinder walls. The greatest pressure observed in the large and small engines is practically the same, 135 to 175 lb. per square inch; but the time of reaching this maximum pressure is somewhat less in small engines than in large ones. Professor Adams pointed out that the expansion curve of the gases after explosion almost coincides with the adiabatic curve, showing that the heat generated by burning after the maximum pressure is reached, is equal to that lost to the cylinder walls and cooling water. The economy of the Crossley "Otto" engines was much higher than that of the Clerk engine, tested at the same time. The results (page 198) revealed an abnormal loss by friction in the Clerk engine.



(Half actual size.)

FIG. 46.—DIAGRAM FROM CROSSLEY OTTO ENGINE.

Speed Regulation.—It is always desirable, and for many purposes—as electric lighting—absolutely necessary, that a prime motor should run steadily, at uniform speed, with widely varying loads. Impulses or blows which suddenly vary the d produce strain in the mechanism unless of excessive strength are very objectionable, and in fact constituted one of the greatest drawbacks in the early forms of internal combustion engine. Some types of the modern gas engine are so designed that an explosion can be made every revolution, but even in these the governor must vary the number or strength of the explosions to suit the load. In the Otto engine we have had only an explosion every alternate revolution, yet this engine was found to work without much variation of speed under the control of a sensitive centrifugal governor for regulating the supply of gas. The simplest and most economical governor is that which cuts off the gas supply completely for one or more cycles, and thus diminishes the number of impulses given to the piston when the speed becomes too great. For electric light purposes, where regularity of speed with slightly changing loads is most important, the ordinary method of governing is somewhat irregular, and it was thought better only to diminish the charge of gas, and thus lessen the energy of each explosion as the speed increases. In an early design the centrifugal governor moved a bowl along the path of a cam fixed upon the shaft; this cam had three or more steps upon it, so that before the bowl is moved entirely out of the way of the cam, less and less opening is given to the gas valve, and consequently less gas enters the cylinder. This cam acts on the gas lever, and according to its position on the shaft will be the particular step of cam that engages the gas lever and the amount of gas cut-off. In this way the gas supply to the cylinder is throttled and the power of the engine is reduced as the speed increases under a light load, so that the same number of impulses being still given the speed is kept fairly uniform. The indicator diagrams, Figs. 46 and 47, show what takes place as the strength of the mixture is diminished until the charge misses fire and there is not an explosion, as the large, medium and small steps on the cam engage the lever. This dilution of charge interferes with the ignition, making it uncertain and late with the weak charges which burn slowly, and the combustion is often incomplete; so that this method of governing can only be applied within a limited range, depending on the richness of the gas and the speed of piston, and it is found more economical in gas consumption to have uniform high compression with full admission or none, and use heavy fly-wheels at high speeds, with two or more cylinders to reduce the variation of speed.

In order to give better regularity for high powers, the Crossley twin engine was devised, in which two precisely similar engines are coupled. The early form had a single slide valve for the supply and ignition of the two charges. The two cylinders were placed side by side within one and the same water-jacket, and their pistons were both coupled to the same crank, so that they moved together.

In a later design of the Crossley double-cylinder engine the cylinders are apart, each with its own water-jacket. The side shaft between the cylinders is driven by worm gear from

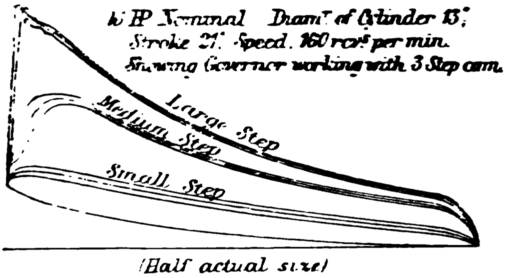


FIG. 47.—DIAGRAM FROM CROSSLEY-OTTO ENGINE.

the main shaft, and carries cams which by means of levers lift the valves for the gas and air admission, ignition and exhaust. The gas admission is regulated by a weighted centrifugal governor, which is worked by bevel gear from the side shaft, and moves a roller along a separate spindle in and out of gear with a cam to admit or cut off gas by acting on the gas-valve levers. Hot tubes are used for firing, timed by levers acting on the ignition valves, page 119, so arranged that when the engine is working at full power the charges are fired alternately in the two cylinders, and there is an explosion every revolution of the driving shaft. The two piston rods are connected to the driving shaft by cranks

each other, so that when one piston is commencing its compression stroke the charge is being fired in the other cylinder, driving forward the other piston. While the piston of the one cylinder is making its forward stroke, drawing in the charge, the piston of the other is going in the opposite direction, compressing the charge in its cylinder; and while the former is making its back stroke, compressing its charge, the other is being driven by the combustion and expansion of gases during its working stroke; the next stroke is firing in the first cylinder and exhaust in the other, and so on.

The products of combustion are expelled through ordinary cast-iron pipes into a cast-iron chamber partly filled with fine shingle (flint pebbles) in a pit, in order **to diminish the noise of the exhaust.** This can also be done in other and simpler ways. From this pit the burnt products pass through a ventilating pipe into the open air. One automatic lubricator acts for both cylinders. There are two large fly-wheels, and the crank-shaft must be of great strength.

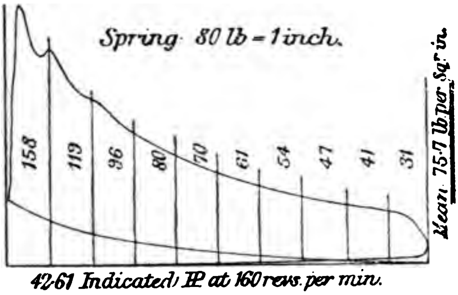
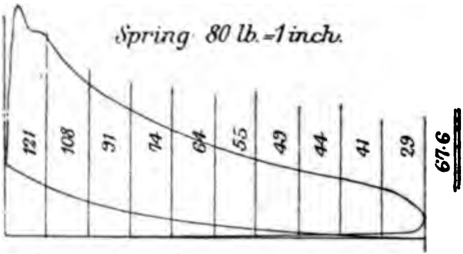


FIG. 48.—INDICATOR DIAGRAM (RIGHT-HAND CYLINDER).

With gas engines, the *rate of gas consumption is less as the power increases*; still, for large powers, coal gas is too costly to compete with the steam engine. Hence **cheap fuel gas** is specially generated for heating and power purposes, and in this way the Crossley engine first used Dowson gas in 1879.

The double-cylinder 16 horse-power nominal Crossley engine of this design, working with Dowson gas, gave upwards of 80 indicated horse-power for about 1·1 lb. of anthracite coal per indicated horse-power per hour. The two indicator diagrams, Figs. 48 and 49, were taken from the two cylinders.

Crossley's Modern Otto Engine.—Messrs. Crossley, of Manchester, have introduced many modifications and improvements in the design of types, parts and working details. The slide valve was at once the most ingenious and delicate organ in the Otto engine. The high temperature of the flame from the explosion burned the edges of the ports, and the high pressure caused escape of flame, unless the strong springs were kept screwed up tightly to hold the slide valve against the back cover. This again caused cutting and wear of the face of the valve, even when well lubricated. The available pressure in the cylinder and the area of the admission port were limited, and the throttling of the charge through the narrow passages, as well as trouble of surfacing the slide valves, presented formidable difficulties. Hence in the 1888 design Messrs. Crossley abandoned the slide valve entirely and adopted **ignition by a heated tube**, with a conical seated lift valve accurately timed and controlled by a lever from a cam on the side shaft. The ignition timing valve opens communication at the right moment between the compressed charge in the cylinder and the inside of a red-hot tube which thus fires the charge.



38·05 Indicated HP. at 160 revs. per min.

FIG. 49.—INDICATOR DIAGRAM (LEFT-HAND CYLINDER).

The details of this arrangement for ignition are shown in Figs. 50 and 51. A piece of ordinary wrought-iron gas tubing T, about $\frac{3}{8}$ or $\frac{1}{2}$ inch in diameter, is closed at the upper end and kept red hot by the flame of a Bunsen burner B, as well as by the asbestos lining R in the chimney. The port C leads directly into the engine cylinder at the charging end, receiving from it a rich mixture of gas and air. The passage between the hot ignition tube T and the cylinder is closed

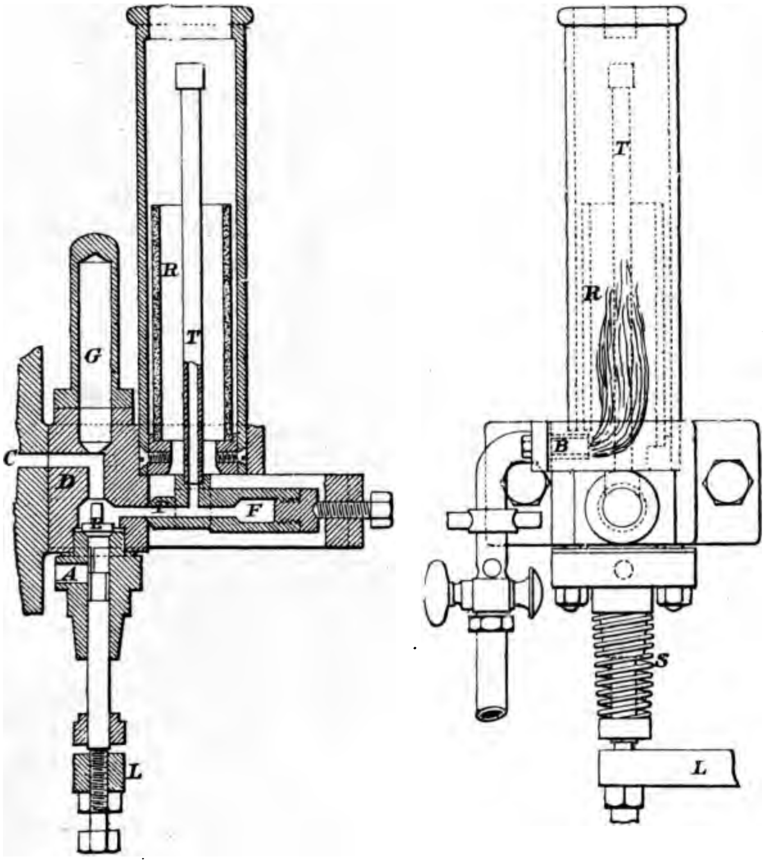


FIG. 50. FIG. 51.
CROSSLEY HOT-TUBE IGNITER.

and opened at the right moment by the *timing valve* E, worked by the lever L from a double cam on the side shaft of the engine. The end E of the spindle is the *timing valve* with stroke $\frac{5}{16}$ inch, which fixes the correct time of firing.

During the compression stroke this ignition valve E is lifted by the lever L, the small end enters the hole D opposite it, closes this elbow-shaped port, and so stops the passage of any flame to the cylinder. At this time any leakage of gas past the peg E, as well as any burnt gases in the ignition tube T, escape freely to the atmosphere through the vent hole or outlet A, so that there is no extra pressure in the tube T during compression in the cylinder.

When ignition is desired the cam on the shaft ceases to hold up the lever L, compressing the spring S, and the valve E is let drop on its seating into the position shown in Fig. 50. Part of the rich compressed mixture from the cylinder rushes into and ascends the hot tube T, where it is ignited, and the flame, spreading back into the cylinder, fires the whole charge at the proper time. The chambers G and F are intended to receive the burnt products from the passage C, so as to keep the portion of combustible mixture which enters and ascends the igniting tube T as pure and free from residuum as possible. The timing valve E should be kept clean, and must fit its seating truly, so as to close and open the passage D promptly, otherwise a slight leakage of compressed gas from C might cause premature ignition.

The loose tube-holder block can be easily taken out by slackening back the set-screw at the end of F, the separation taking place at the mitre joint at P. Then the old tube can be removed and a fresh one screwed in.

The red-hot tube T becomes burnt in a peculiar way and requires frequent renewal. The burning makes the metal swell, forming brittle carbide of iron, which finally chokes up the tube. An igniter tube made of wrought iron lasts only about 30 hours. This *short life* is due to the high temperature at which the tube is worked, and partly to the action of the timing valve E, which causes a *sudden rush* of the highly compressed charge into the red-hot tube T, and rapidly chills its inner surface.

Porcelain ignition tubes are found to last for several months, and although their life is rather uncertain they are now generally used in the gas engine. The porcelain tube is open at both ends, clamped by an adjusting screw against asbestos washers. The upper end has an extension of iron tube, and the lower end opens to the ignition port with timing valve.

When slide valves were given up, the charge of gas and air was admitted to the cylinder by separate lift valves of mushroom type, held on their conical seatings by spiral springs, and lifted by levers worked from cams on the side shaft. These valves are made easily accessible and can be ground on their seats when necessary. In this arrangement the ports and valves are readily proportioned to the proper size, to prevent throttling of the charge during admission, which was difficult to avoid in the slide valve.

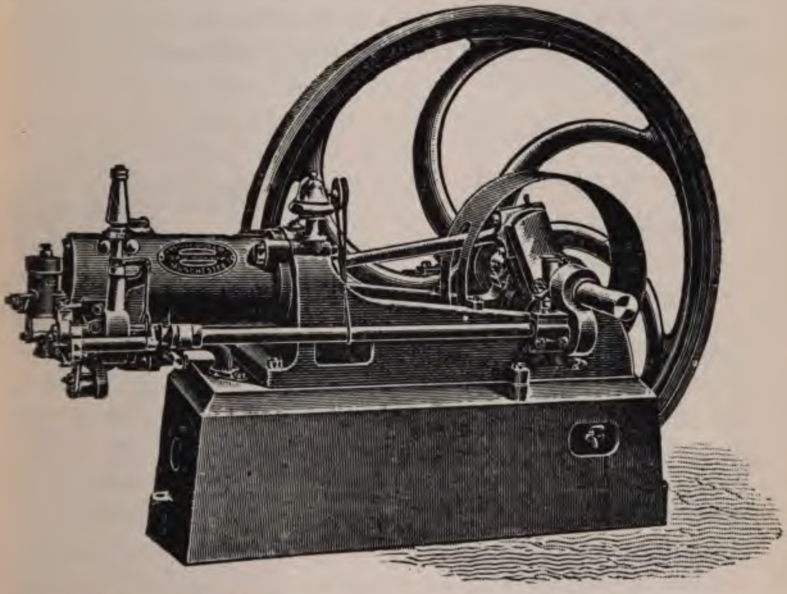


FIG. 52.—CROSSLEY'S 7-H.P. OTTO GAS ENGINE, 1889 TYPE.

The 1889 type of Otto engine, as built by Messrs. Crossley, is seen in external view, Fig. 52, whilst Fig. 53 is a longitudinal section, and Fig. 54 an end elevation. This represents a 7 horse-power nominal, giving a maximum of 13 brake horse-power with coal gas when running at 180 revolutions per minute. The bore of the cylinder is 8½ inches in diameter, and the length of stroke 18 inches.

The old cross-head guide and slide on the piston are dispensed with, and a long trunk piston alone is used in the cylinder. The piston P, Fig. 53, with its rings, is at the end of its in stroke, and the gudgeon pin at its centre is directly joined to the crank pin by the connecting rod, the centre line of which, at mid-stroke, is indicated by the broken line. In one part of the engine base F there are baffle-plates B, to silence the inrush of air through the openings A to the inlet pipe D. The gas supply is admitted by a lift valve to the gas channel G, where it mixes with the air; and the charge is admitted by the conical seated valve V to the compression space C in the cylinder. All the valves are conical seated of the lift type, and operated by levers from cams on the side shaft. I is the ignition port open to the hot tube H, Fig. 53, by the timing valve as in Fig. 50, page 119. The exhaust port R opens to the exhaust valve, in a box at the side of the cylinder, allowing the burnt gases to escape by the pipe E, Fig. 54.

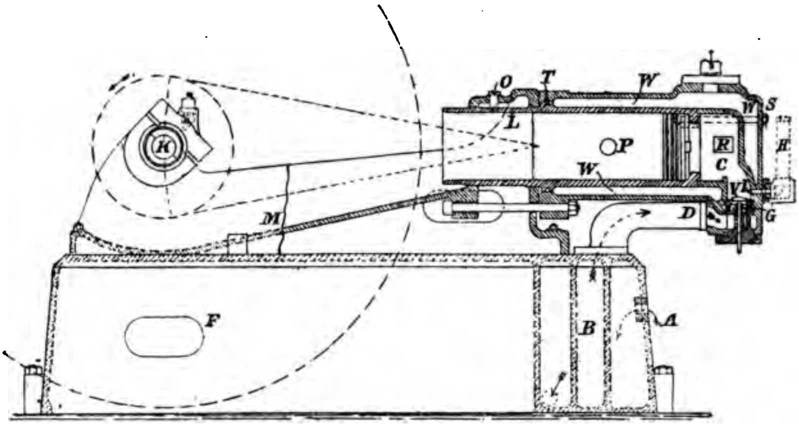


FIG. 53.—CROSSLEY'S 7-H.P. OTTO ENGINE (LONGITUDINAL SECTION).

The compression space C and the cylinder have a continuous cooling water-jacket W, in the space between the outer casing and the cylinder liner. This liner L, in which the trunk piston works, is made of special hard cast iron, and can be easily replaced when worn. The liner is held tight against the back end of the cylinder by four bolts S, drawn through the compression space. The front end of the liner, next the crank shaft K, is fitted into the bed M, and has an india-rubber ring T to keep a water-tight joint when the liner expands or contracts. The whole cylinder is bolted against a faced flange on the bed M, which is seated on and firmly bolted to the base F. The noisy bevel wheels, geared 2 to 1 between the crank-shaft and cam shaft, are replaced by worm or skew gear, giving a neater and quieter drive. The cam shaft is driven at half the speed of the crank-shaft. But these gear wheels are still placed outside the frame, so that with a second fly-wheel on the shaft outside of these gear wheels when uniform speed is desired, and a driving pulley sometimes on the outside of that again, the pull on the shaft is a long way from the bearing, giving an objectionable overhang, which necessitates an extra strong crank-shaft to withstand bending, and is severe on the bearing.

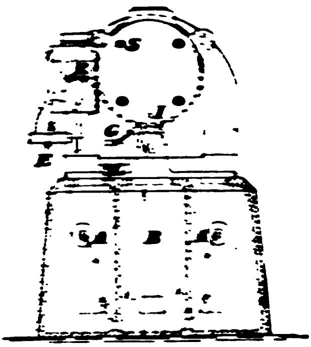


Fig. 54.—Crossley's Otto Engine (End Elevation).

Messrs. Crossley still adhere to the old method of utilising the centrifugal governor for moving a roller or bowl in and out of gear with a cam on the side shaft to operate the gas valve, either admitting a full charge or cutting off the gas completely. Here the weak point is that the governor may get "jostled" by attempting to move the roller when the cam is almost in its path; the roller engages with the cam, but only so slightly that it gets "jarred off." This action also causes half charges to enter the cylinder, which are sometimes unfired and cause explosions in the exhaust pipe.

It is necessary to grind the valves to fit truly on their seatings and prevent any possible chance of leakage, which would destroy the compression and cause trouble. Thus if gas leaked down into the silencing chamber B it would likely be fired there and shatter the base plate.

The cycle of operations in the cylinder is practically the same as in the early form of Otto engine, with slight modifications of the times of opening and closing the valves to give the best results. The **valve setting** by cams to operate the levers can be readily followed on a diagram, Fig. 55, showing the position of the crank when each operation takes place. The large circle is drawn to represent the path of the crank pin, and the diameter of the circle represents the whole travel or stroke of the piston. It will be seen that the valves do not open for the four operations exactly at the moment the piston is at the end of each stroke, or when the crank is passing the dead centres. In *charging*, the air valve opens and the exhaust closes slightly before the end of the exhaust stroke, and the gas valve opens as the crank passes the in-centre, in order to retain some residual products and avoid too great a vacuum in the cylinder at the end of the exhaust stroke. Then in the charging stroke the gas valve closes when the crank is at an angle of about 30 degrees from the out-centre, and the air valve remains open until the piston has just begun its compression stroke. The cylinder is thus well filled

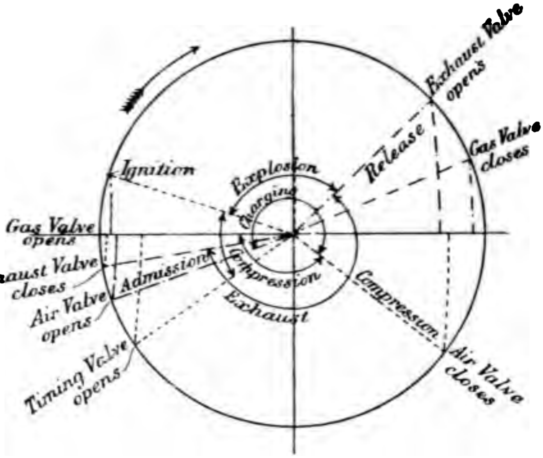


FIG. 55.—DIAGRAM OF VALVE SETTING.

with the fresh charge for *compression*, provided the ports are so designed that there is free admission of the charge and that no throttling occurs. The narrow passages in the old slide valve seriously reduced the charge taken into the cylinder, and the pressure was considerably below atmospheric pressure at the end of the charging stroke. This difficulty was removed, and higher compression made easy, by the adoption of lift valves combined with the hot-tube igniter. Before the end of the in stroke the timing valve is opened to allow some of the compressed charge into the ignition tube, as in Fig. 50, in order that there may be time for the flame to travel back to the compression space, and *explosion* will take place promptly as the piston begins its working stroke. Towards the end of this expansion or working stroke, when the crank is yet at an angle of about 45 degrees from the out-centre and the piston speed slows down, the *exhaust* valve opens to give release, to allow free escape of the burnt gases, and prevent too high back-pressure in the cylinder and exhaust pipe during the return or discharge stroke of the piston.

The modern stage in the development of the Crossley-Otto engine began about the end of the year 1888, before the expiry of Otto's master patent in 1890. This is marked by the Crossley engine with hot-tube ignition, entered for the competition at the **Society of Arts trials** of motors for electric lighting. For this purpose the points of merit considered of importance were: regularity of speed under varying loads; power of automatically varying speed to suit the load of lamps; noiselessness; cost of construction, cost of fuel when running, and of maintenance.

The judges were Dr. John Hopkinson, F.R.S., Professor A. B. W. Kennedy, F.R.S., and Mr. Beauchamp Tower, who conducted careful and scientific tests of three gas engines, an Atkinson "Cycle," a Crossley-Otto, and a Griffin, at South Kensington, London, in September 1888. The efficiency tests included a six hours' continuous run for each engine at full brake power, a three hours' at half power, and running light. Heat accounts for each trial were drawn up, and the behaviour of the engines carefully observed. Other tests were made, as to cyclical variation of speed, regularity of running and of governing when driving a dynamo for electric lighting.

The Atkinson engine gave exceptionally good results, with the lowest gas consumption, and in other respects worked very satisfactorily. The Crossley engine used much less gas and cylinder lubricant per brake horse-power than the Griffin engine; but the regularity of speed of the Griffin was distinctly better than that of the Crossley.

The Crossley-Otto engine was 9 nominal horse-power; the cylinder 9·5 inches in diameter by 18 inches stroke; the ratio of the compression space to the volume swept by the piston was taken at $\frac{4}{10}$. In the full-power trial the mean pressure before ignition was 76·3 lb. per square inch (absolute), the atmospheric pressure that day being 14·9 lb. per square inch. The temperature of the cylinder is raised by this compression and the corresponding high explosion, giving greater power than the early form of Otto. At half power the explosions occur but seldom. When the speed increases the governor cuts off the gas supply, so that during that cycle only cold air is drawn into the cylinder, mixed and compressed with the residual burnt gases and pumped out into the exhaust. The cylinder and ports are cooled by this action as well as by the water-jacket. Hence a greater weight of pure gas and air will be admitted for the next charge, giving an extra strong explosion with a mean effective pressure higher than that in the more frequent explosions at full power. In the full-load brake trials, the greatest average speed during any quarter of an hour was 161·8, and the least 155·1 revolutions per minute. In the special speed trials the percentage variation in speed with full load and running light was 6·57. The engine had one fly-wheel 65·5 inches diameter, 9 inches broad on face, and weighing 1652 lb. The principal results from the Crossley engine, as given in the report of trials by Professor Kennedy, will be found in the table on the opposite page.

The actual calorific or heating value of the coal gas, at standard temperature and pressure, was determined by calculation from the results of analyses of samples taken during the trial. The latent heat of the steam produced was deducted from the calorimetric values of the hydrogen constituents, because this heat only appeared in condensing the steam in the calorimeter, and is not actually generated as heat in the gas-engine cylinder.

TRIALS OF CROSSLEY-OTTO GAS ENGINE (Society of Arts, London, 1888).

Date	September 19	September 20	September 20
Duration of trial	6 hours	3 hours	½ hour
Power	full	half	empty
Revolutions per minute	160·1	158·8	161
Explosions per minute	78·4	41·1	10·2
Pressure before ignition (absolute) lb. per sq. in.	76·3	..	..
Explosion pressure (absolute) lb. per sq. in.	196·9	196·2	148
Mean effective pressure ,,	67·9	73·4	66·7
Indicated horse-power	17·12	9·73	2·19
Brake horse-power	14·74	7·41	0
Mechanical efficiency	86 per cent.	76 per cent.	..
Indicated horse-power spent in driving engine alone	2·38	2·31	2·19
Gas used per hour (main)	351·8 cub. ft.	202·6 cub. ft.	49 cub. ft.
,, ,, (ignition)	3·5 ,,	3·2 ,,	..
,, ,, (total)	355·3 ,,	205·8 ,,	..
Gas per I.H.P. hour (main)	20·55 ,,	20·8 ,,	22·38 cub. ft.
,, ,, (total)	20·76 ,,	21·2 ,,	..
Gas per brake H.P. hour (total)	24·1 ,,	27·77 ,,	..
Heating value of gas, B.Th.U. per cubic foot (calculated from analysis)	626	..	..
Cooling water per hour	713 lb.	480 lb.	..
Rise of temperature of water	128° F.	102·3° F.	..
Thermal efficiency:—			
Heat of combustion turned into work indicated in cylinder	21·2 per cent.	20·9 per cent.	19·4 per cent.
Heat lost by jacket water	43·2 ,,	41·1 ,,	..

Crossley Scavenging Engine.—Mr. F. W. Crossley and Mr. J. Atkinson devis means of “scavenging” or sweeping out the residual burnt gases from the clearance space of the Crossley-Otto engine. The engine is fitted with a long exhaust pipe, and the puff or discharge of the burnt gases from the cylinder at a pressure of 40 or 50 lb. per square inch, after an explosion, sets up a rapid motion and pulsation of the gases in the exhaust pipe, carrying them forward and causing a partial vacuum behind. The length of the exhaust pipe, about 65 feet, is carefully adjusted so that the partial vacuum is produced in the pipe at the cylinder end when the piston is finishing the exhaust stroke. Advantage is taken of this vacuum by opening the air-inlet valve early, and keeping the exhaust valve open late, so that both are open at the same time during a quarter of a revolution of the crank. A current of pure air is thus drawn through the clearance space, sweeping out the burnt gases, and continues during part of the suction stroke to replace at least a portion of the burnt gases by pure air. When the exhaust valve closes the gas valve opens, so that the cylinder is filled with nearly pure air and gas during the charging stroke. In the diagram, Fig. 56, when the crank pin is in the position A in the working stroke, the exhaust valve is opened, and is kept open until the crank is at B, past the ordinary closing position C at the centre. The air-admission valve is opened when the crank is at D, and the in-rush of fresh air "scavenges" or sweeps out part of the burnt gases from the clearance space into the vacuum in the exhaust pipe during the quarter revolution of the crank from D to B. At B the exhaust valve closes and the gas valve opens, then gas and air are drawn into and fill the cylinder with a pure mixture of gas and air during the remainder of the suction stroke.

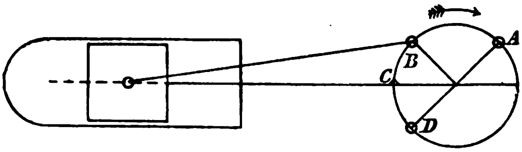


FIG. 56.—DIAGRAM OF VALVE SETTING, CROSSLEY'S SCAVENGING ENGINE.

It is necessary to make the valve ports and clearance space at the end of the cylinder rounded in shape, as shown in Figs. 57 and 60, to facilitate the flow of the current of air from the inlet valve V, through the exhaust valve R, and out by the exhaust pipe E.

The end of the piston P is concave in shape, to make the clearance space C as nearly spherical as possible. A continuous water-jacket W surrounds the cylinder, exhaust valve box and spindle of the valve.

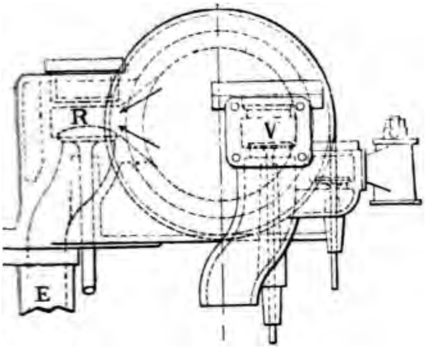


FIG. 57.—END ELEVATION.

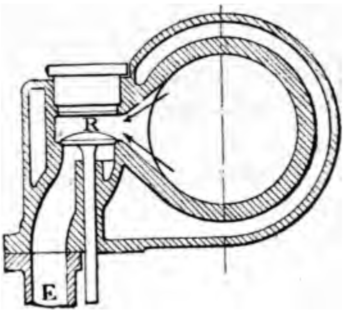
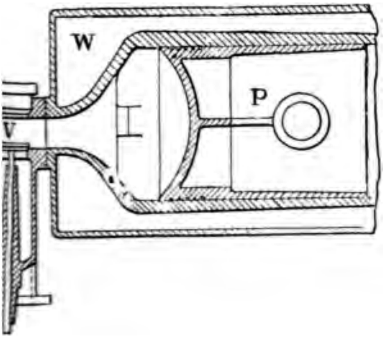


FIG. 58.—CROSS SECTION.



IG. 59.—LONGITUDINAL SECTION.

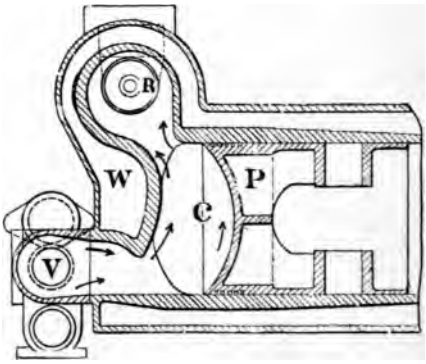


FIG. 60.—SECTIONAL PLAN.

CROSSLEY-OTTO SCAVENGING ENGINE.

In the light spring diagram Fig. 61, taken during the exhaust and suction strokes, it is seen by the exhaust line that the pressure in the engine cylinder falls about 2 lb. below atmospheric pressure towards the end of the stroke. This partial vacuum causes the inrush of fresh air by the inlet valve V, sweeping some of the residual burnt gases out of the clearance space C, through the exhaust R, Fig. 60, whilst the crank moves from position D to B, Fig. 56. The pure fresh charge of explosive mixture which fills the cylinder is easily ignited, and gives remarkable economy at full load.

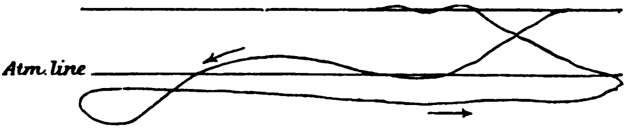


FIG. 61.—LIGHT SPRING DIAGRAM. CROSSLEY SCAVENGING ENGINE.

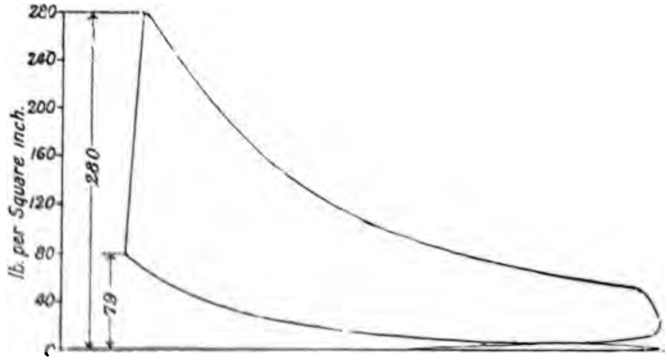


FIG. 62. CROSSLEY SCAVENGING ENGINE WITH COAL GAS.

Engine, 14 horse-power nominal; diameter of cylinder, 11½ inches; length of stroke, 21 inches; revolutions per minute, 173·63; mean pressure, 98·75 lb.; pressure before ignition, 79 lb.: brake horse-power, 30·01; gas consumption per B.H.P. per hour, 16·49 cubic feet; gas per I.H.P. per hour, 14·5 cubic feet.

The indicator diagram, Fig. 62, taken from a Crossley scavenging engine during a brake test by Mr. Atkinson, shows a total mean pressure of 98·75 lb. per square inch in the cylinder with Manchester coal gas, and the charge compressed to 79 lb. per square inch before ignition. The

gine gave 39·9 horse-power on the brake, with a gas con-
nption of only 16·49 cubic feet per brake horse-power per
r. Taking the heating value of Openshaw coal gas at the
r estimate 640 B.Th.U. per cubic foot, these figures show
t the engine converts 28 per cent. of this heat into work.

Mr. D. Clerk made a test of a 4 (nominal) horse-power
ossley scavenging engine at Openshaw, in 1894, for publica-
n. The cylinder was 7 inches in diameter with a 15-inch
oke, and running at 200 revolutions per minute gave a
an pressure of 100 lb. per square inch, 14 indicated horse-
ver and 12 brake horse-power on a gas consumption of
cubic feet per brake horse-power hour. The compression
ce was 34 per cent. of the volume swept by the piston, the
ssure before ignition 87·5 lb. per square inch, and the
ximum explosion pressure 275 lb. per square inch. The
gine converts 25 per cent. of the total heat of combustion
the gas into indicated work, on the assumption that 3·736
ic feet of the gas used supplies heat equivalent to 1 horse-
ver hour, or that its heating value is equivalent to 530,000
t-pounds per cubic foot.

In this way the 7 horse-power nominal engine, page 121,
ered to scavenger type, and with high compression of
rge, the frame and shaft being strengthened, would develop
ater power with a low consumption of gas at full load.
though the frequency of the forces due to high compression
d violent explosions are rather trying on the engine, still
stresses are greater from an abnormally heavy charge after
niss or cut-out in the ordinary 7 horse-power engine, as in
icator diagram Fig. 64, with Dowson gas.

Scavenging is of special benefit in large engines working
ntinuously at full load with Dowson gas or other cheap fuel
s, and it is necessary with high compression. The residual
rnt gases being swept out, and the cylinder and ports
oled by the current of fresh air, (1) a greater quantity of gas
n be drawn into the cylinder every charge and highly com-
essed, giving greater power from a given size of cylinder;
) another great advantage of scavenging is that in large
ngines it enables very high compression to be used without

risk of premature explosion or early ignitions during compression, and there is less tendency to back-firing in the passages, usually due to the presence of residual hot burnt gases. Ignition of the pure mixture is rendered more certain and regular when weak gas or varying quality is used, whereas without scavenging this weak mixture further diluted with burnt gases is apt to miss fire or burn imperfectly, and to cause explosions in the exhaust or air pipes. [illegible] the result is more rapid and complete combustion, giving greater economy of fuel and more power (see page [illegible]).

The indicator diagram, Fig. 63, is from a Crossley scavenger of 30 nominal horse-power, with [illegible]-inch cylinder and 24-inch stroke, giving at [illegible] revolutions per minute about 100 indicated horse-power. The same engine using coal gas, with a compression of 75 lb. per square inch before ignition, gives about 120 indicated horse-power.

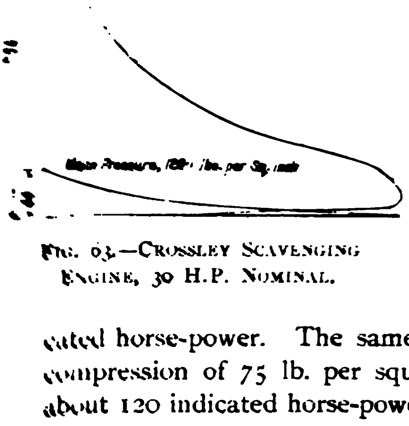


FIG. 63.—CROSSLEY SCAVENGING ENGINE, 30 H.P. NOMINAL.

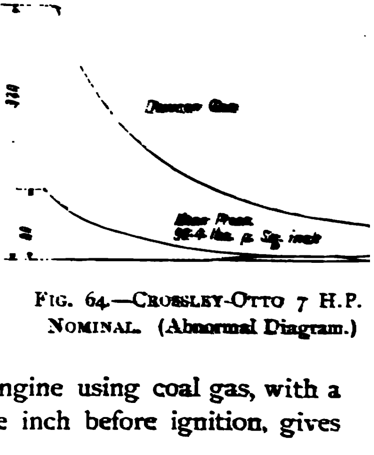


FIG. 64.—CROSSLEY-OTTO 7 H.P. NOMINAL. (Abnormal Diagram.)

The vacuum obtained with the long exhaust pipe is rather difficult to adjust, and under ordinary working conditions, when the engine is governing at half load or varying load, this method of scavenging is not found so satisfactory as the consumption at full load would indicate. This result may be also partly due to the effect of variation in speed on the forced motion of the gases in the exhaust pipe. These drawbacks are not felt when the scavenging air is forced through the combustion chamber by means of a pump, as in a positive [illegible] engine like the Premier (see page 229).

Messrs. Crossley build a large variety of designs of the Otto cycle gas engine, to give from one-third of an effective horse-power up to 200 horse-power, and the large double-cylinder engine indicates 400 horse-power with Mond gas. About 3000 of these engines are sold every year. Until 1898, upwards of 33,000 gas engines were sold by this firm alone, and with the Gas-Motoren-Fabrik, Deutz, the German makers, there were 62,961 Otto engines sold from 1877 to the end of 1897, giving a total of 521,652 brake horse-power.

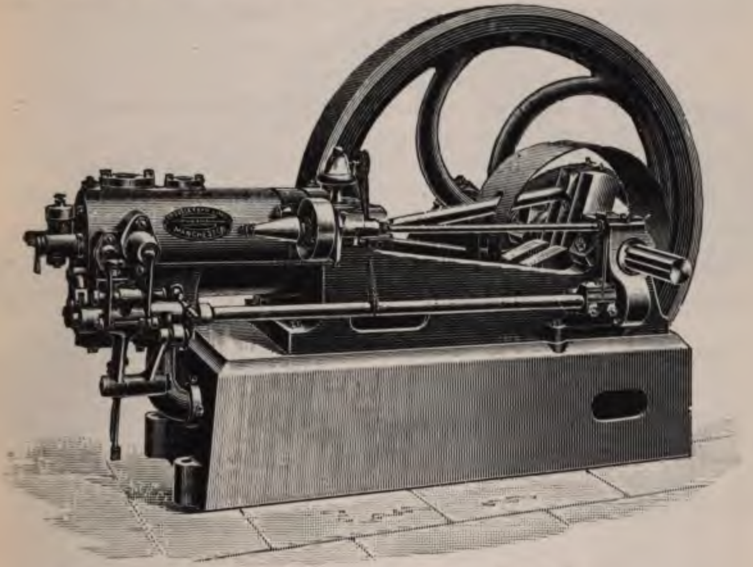


FIG. 65.—CROSSLEY GAS ENGINE, 1898 TYPE.

The 1898 pattern of the Crossley electric light engines, Fig. 65, is in sizes of 4 to 24 effective horse-power, running at 180 to 200 revolutions per minute. The gas and air inlet valves are horizontal, opening direct into the compression space, thus reducing the surface of passages; and the exhaust valve is vertical on the opposite side of the cylinder. These valves are easily got at. In some large engines the exhaust valve box at the side is made part of the cylinder end casting. This overcomes the trouble of leakage at the joints of the water-jacket to cool the exhaust valve spindle. Otherwise the expansion by the high temperature of the gases and the vibration of the engine would tend to break the joints. The horizontal type of governor is adopted, bringing it nearer the gas valve and giving the convenience of driving from the crank-shaft, as found by other makers. The vertical centrifugal governor driven by bevel gearing from the cam shaft is affected by the motion of the latter when there is backlash and cams are worn, and the small pinion on the governor shaft is very difficult to gear to work satisfactorily for any length of time, as there is always a good deal of wear and tear, and the gearing on the cam shaft is objectionable after it becomes worn. With the horizontal governor driven direct from the crank-shaft, the sensitiveness of the governor is longer maintained.

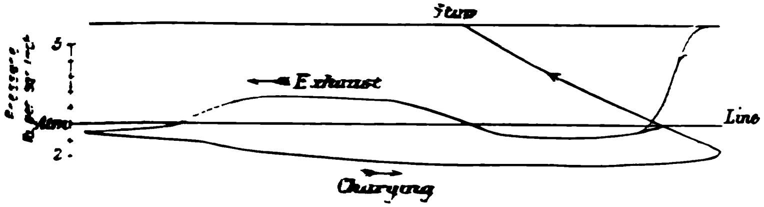


FIG. 66.—INDICATOR DIAGRAM (LIGHT SPRING). CROSSLEY GAS ENGINE.

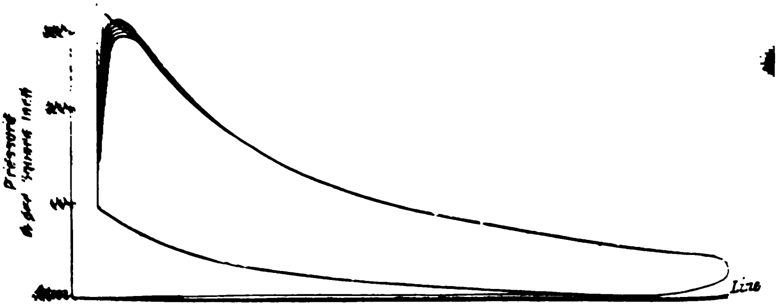


FIG. 67.—HALF-MINUTE INDICATOR DIAGRAM. CROSSLEY GAS ENGINE, OCTOBER 4, 1899.

Speed, 169·35 revolutions per minute; 66 explosions per minute; mean pressure, 85·7 lb. per square inch.

On October 4th, 1899, the Author made a brake test of Crossley gas engine with cylinder 11½ inches diame by 21 inches stroke, and normal speed 170 revolutions per minute. The mean speed of piston was 600 feet per minute. This new engine had been at work daily for two months, and was therefore tested under most favourable circumstances, with a steady load applied by a rope brake on the fly-wheel, first at half power and continuing at full power. Simultaneous observations for the various measurements were made every five minutes, when indicator diagrams were taken. The number of explosions every minute was recorded. At intervals, continuous half-minute indicator diagrams were taken, shown in Fig. 67, and light spring diagrams, Fig. 66, for the pumping strokes. The performance of the engine was regular and in every way satisfactory.

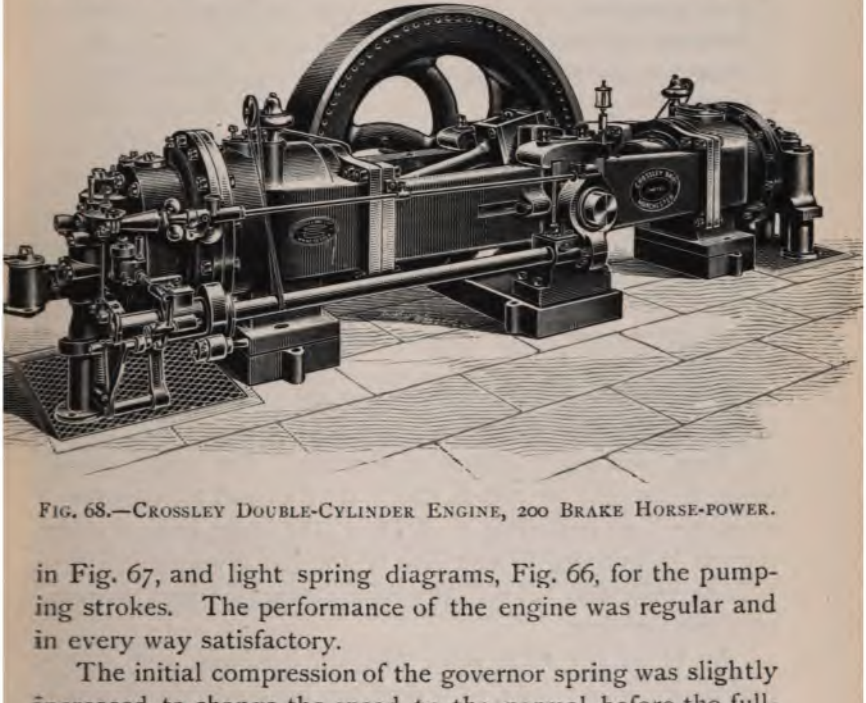


FIG. 68.—CROSSLEY DOUBLE-CYLINDER ENGINE, 200 BRAKE HORSE-POWER.

The initial compression of the governor spring was slightly increased to change the speed to the normal before the full-load trial. The governor, by means of a lever, moves a notched sliding block at the end of the gas valve spindle, so that the push-piece either engages or misses it. The speed was remarkably steady; the extreme range of the mean speed for every five minutes was from 167·4 to 166·4 at half load, and 170 to 168·4 at full load.

Results of Trial—Crossley Gas Engine, October 4, 1899.

	Full Load.	Half Load.
Duration of trial . .	1 hour	½ hour
Revolutions per minute (mean) . .	169·35	167·1
Explosions . . .	65·2	34
Pressure before ignition above atm., lb. per sq. in.	95	95
Explosion pressure	285	285
Mean effective pressure after deducting pumping, lb. per square inch . . .	83·5	89·5
Indicated horse-power . . .	30	16·8
Brake horse-power	26	12·7
Mechanical efficiency, per cent.	86	76
Gas used per hour including ignition, cubic feet .	465	268
Gas per indicated H.-P. hour " " .	15·5	16
" brake " " " " .	17·9	21·1
Heating value of gas as used by the engine, effective, B.Th.U. per cubic foot	600	600
Thermal efficiency:—	per cent.	per cent.
Heat turned into work done on the piston .	27	26·5
" " on brake . .	23·7	20·1

The effective heating value of the gas as used in the engine, tested in the calorimeter, was 600 B.Th.U. per cubic foot at 58° Fahr. and 29·6 inches of mercury. The total calorific value of the gas is 700 B.Th.U. at 0° C. and 29·9 inches of mercury; and deducting 60 B.Th.U., the latent heat of steam formed in burning a cubic foot of the gas, gives the effective heating value 640 B.Th.U. per cubic foot at standard temperature and pressure.

At 2*s.* 6*d.* per 1000 cubic feet, the gas cost just over a half-penny, from 0·54*d.* to 0·63*d.* per hour per useful horse-power available at the driving pulley.

The modern **double-cylinder engines** are made of the girder frame type, with the two cylinders placed end-to-end, Fig. 68, as in the old Stockport engine (page 207). This arrangement of cylinders with the Otto cycle cannot possibly give one explosion every revolution. At full power two explosions follow each other in one revolution, and there are two pumping strokes in the next revolution. Thus the work is not evenly distributed, exerting a variable turning moment on the crank-shaft. The engine is well balanced, with a good grip of the foundations, and the centre line low, whilst the main girders give great strength and stiffness. The combustion chambers are separate castings bolted to the end of the cylinders, with the gas and air valves at the extreme end. Each engine has independent gears, and either can be disconnected. Both connecting rods are coupled to the same crank pin, one rod having a forked end. The horizontal type of governor is used, and ignition is by hot porcelain tubes with timing valve control. These engines give 200 effective horse-power at 160 revolutions per minute with coal gas.

At Winnington, in Cheshire, during 1898 and 1899, an engine of this type direct-coupled to a dynamo gave 89 electrical horse-power with clean Mond gas, on the average consumption 1·8 lb. of bituminous slack per kilowatt-hour. The engine ran, day and night, 98 per cent. of the total hours in each year. In 1900, during a trial run of two hours, the first 400 horse-power Crossley engine using Mond gas gave 377·9 indicated horse-power at 152·4 revolutions per minute. The charge was compressed to 80 lb. per square inch above atmospheric pressure, explosion pressure 240 lb., and the mean indicated pressure 51·4 lb. per square inch. The consumption of fuel was 60 cubic feet of Mond gas per indicated horse-power hour, and the corresponding slack used in the Mond producer was 1·03 lb. per indicated horse-power hour. The calorific value of the Nottingham slack was 12,200 B.Th.U. per lb., and of the Mond gas 162 B.Th.U. per cubic foot, which makes the thermal efficiency of the engine 26·2 per cent. Deducting the power spent in pumping strokes, the net indicated power was 348·7 horse-power; loss by engine friction 34·9 horse-power, leaves 313·8 brake horse-power, and the useful output 291·8 electrical horse-power (see page 584).

In these large engines working with cheap fuel gas, the exhaust valves and pistons are made hollow and cooled by water circulating through them, to allow of high compression of the charge without premature ignition troubles. The exhaust valves are fitted in detachable boxes to be easily replaced or renewed. The ends of the cylinder water-jackets have detachable covers to avoid the risk of broken breech-ends, and to enable the water-jackets to be cleaned. The engines are started with compressed air at 60 lb. per square inch.

A few engines of the smallest sizes, from $\frac{1}{3}$ to 4 brake horse-power, are still made of the *vertical* single-cylinder type, Fig. 69, for purposes where considerations of room occupied and simplicity of working parts are important. The exhaust valve opens about 30 degrees before the out-centre and closes at the in-centre. Then the air valve opens and shortly afterwards the gas valve, both remaining open until the piston turns to commence the compression stroke. This handy little ***domestic motor*** is fitted with a simple form of Holt's inertia governor, worked by a small crank at the end of the side shaft, and which regulates the speed by cutting off the gas. Fig. 69 is a view of the 3 horse-power nominal, cylinder 7 inches diameter by 10·5 inches stroke. The working load, at 200 revolutions per minute, is 4 effective horse-power.

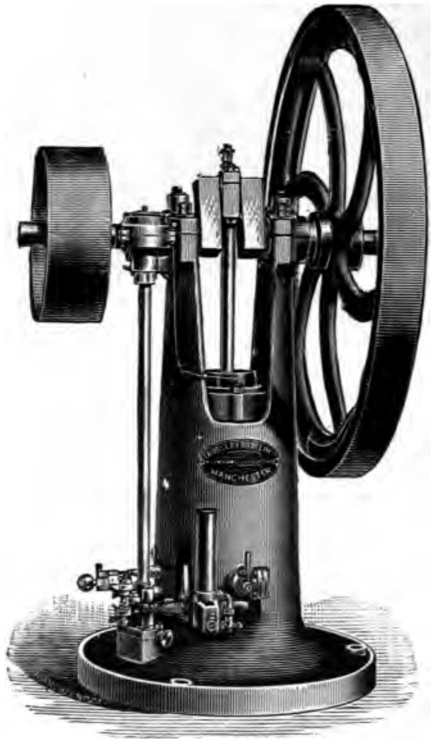


FIG. 69.—3 HORSE-POWER NOMINAL CROSSLEY VERTICAL ENGINE.

CHAPTER VI.

ATKINSON GAS ENGINES.

FOUR remarkable engines were brought out by Mr. James Atkinson, who has devoted the whole of his time and great inventive skill to gas engines. His first patent, dated 1879, No. 3213, was for a *compression gas engine.* This engine is noteworthy for four novel features : (1) it was the first compression gas engine ever made *without* a *slide valve*; (2) there was an *impulse every revolution* of the crank shaft; (3) the charge was expanded to more than the original volume ; and (4) it was one of the *first known* instances of a *gas engine working with a hot-tube ignition* almost identically the same as that in use at the present day.

In 1881 he patented improvements in the non-compression engine, and by ignition immediately after admission every revolution, effected considerable economy. He also worked for years with compound compression engines, but his experience led him to give up this idea and to perform the whole of the expansion in one cylinder. He tried a pump, consisting of the inner end of the working cylinder, and with an impulse every revolution ; also one with a separate pump, and in this way obtained high efficiency, which compared favourably with other engines then in the market.

Differential Engine.—Realising the two great sources of waste as the **water-jacket** and the **exhaust**, he designed his next engine to do the work very quickly, so the "differential" did it in *one-fourth* the time of any other engine, that is to say, the working agent in the cylinder expanded to the original volume during one-eighth of a revolution or one-quarter the time taken in the Otto engine, and still farther to *double its original volume in a quarter of a revolution, that is* *in half the usual time.* The Atkinson "*differential*" *engine* has also four novel features: (1) the *whole* of the burnt gases are expelled from the cylinder; (2) the charge is allowed to expand beyond its original volume; (3) there is an explosion every revolution, the four operations of the Beau de Rochas cycl being performed by two pistons in the one cylinder during four strokes of different lengths, all in one revolution of th crank-shaft; (4) the method of timing the ignition by hot tube. All valves are automatic lift valves of the mushroom type.

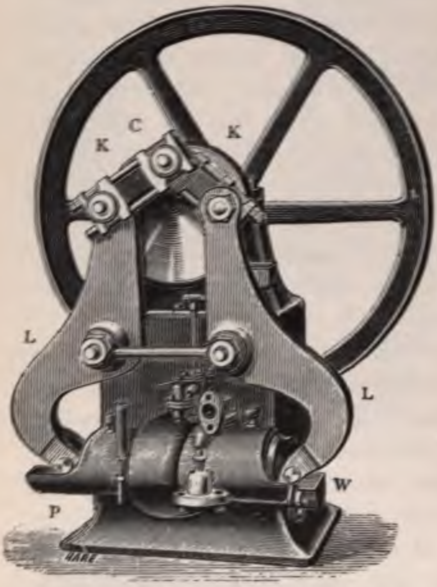
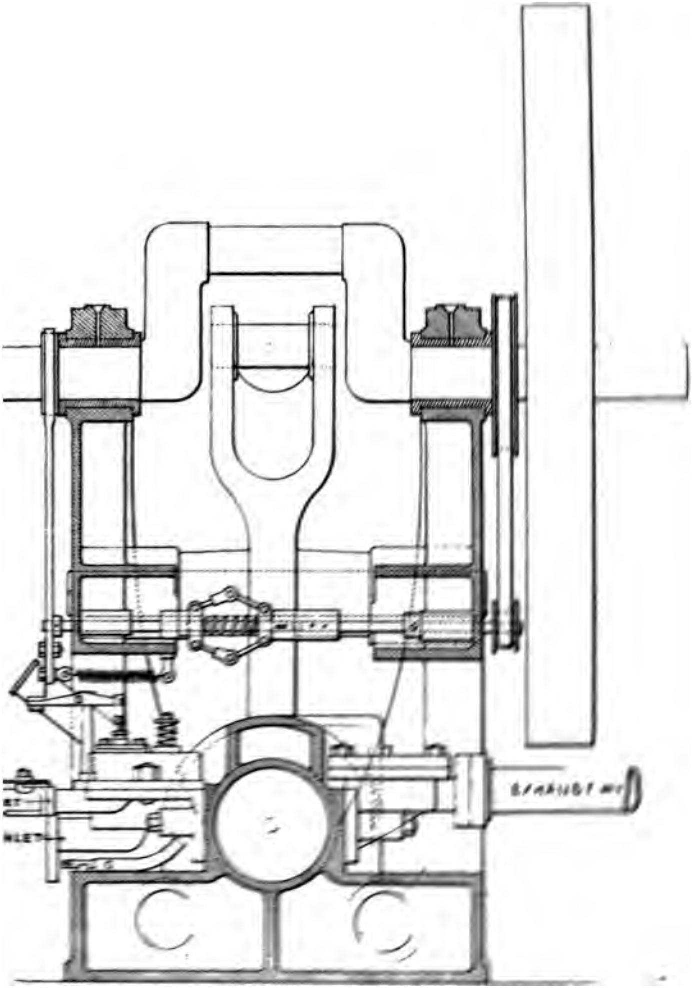


FIG. 70.—ATKINSON DIFFERENTIAL GAS ENGINE.

The external view Fig. 70, shows th general appearance o the first engine buil hurriedly for the Inventions Exhibition i 1885. It attracted muc attention by its nove motion, its simplicity and the great advanc it marked in the development of gas engine on the lines indicated b theory.

In this engine th one cylinder, used bot as pump and mot cylinder, is fixed outsid the frame, but in th next design, shown i the vertical cross sections, Figs. 71 and 7 the cylinder is placed inside, thus rendering the machi better balanced. The horizontal cylinder, Fig. 70, is open a both ends, and fitted with two pistons—the left-hand one w shall call the pump piston P, and the right-hand one the motor piston W. The pistons are connected by links to the lower ends of the levers L, L working on the centres F, F fixed in the main frame of the engine. These levers are hed at their upper ends by short connecting rods K, K to rank pin C, fixed in a disk which is keyed on the main



G. 71.—Atkinson Differential Engine (Sectional Elevation).

t. These short connecting rods are an essential feature he design, for it is the angularity of the rods and arms causes the peculiar differential motion of the pistons.

Self-acting valves A and E, Fig. 72, prevent the air, gas and exhaust passing in the wrong direction, whilst the sensitive centrifugal governor, Fig. 71, controls the admission of gas. Except this governing gear there is not an eccentric or cam in the engine; the suction and exhaust valves are automatic, whilst the pistons do the work of the ordinary slide valve, thus dispensing with the delicate and intricate details in the ordinary slide valves. This simplicity of parts for admitting and firing the charge was one of the important points in the design, but the arrangement of links and levers was troublesome mechanically. All previous practical gas engines were very delicate machines; slide valves required to be fitted and adjusted with the greatest accuracy; any neglect in lubrication, or too great pressure in screwing up, was likely to cause abrasion, throwing them out of order, and such engines could only be repaired by the makers, or engineers who had a lot to learn before they could repair or work them; whereas the wearing parts in this engine are only pistons, and round pins with their bearings, the latter being made adjustable for wear, and having a large area of bearing surface so as to last long, and when worn an ordinary engineer can repair them.

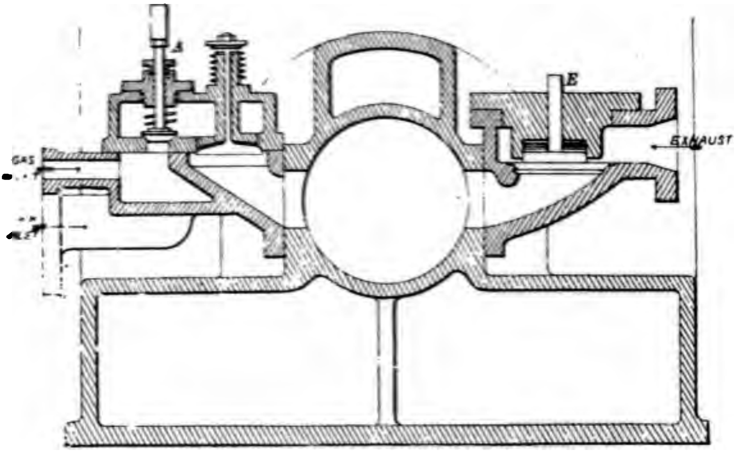


FIG. 72.—ATKINSON'S DIFFERENTIAL ENGINE (SECTIONAL ELEVATION).

The *igniting tube*, of wrought iron or ordinary gas pipe, is open at its lower end to a small hole drilled through the wall of the cylinder and closed with a screw cap at its upper end. It is kept red hot near the cylinder by a Bunsen burner, so that when the pumping piston P, Fig. 70, uncovers the small hole a portion of the charge rushes into it, is ignited, flashes back into the cylinder and fires the charge. These ignition tubes, when made of wrought iron, get burnt into a brittle carbide, become choked up and require frequent renewal, their average life in this engine being 180 hours.

The middle part of the cylinder is surrounded with a water-jacket, but *owing to the increased rate at which the work is done, and the increased expansion, a much smaller quantity of water than usual suffices.*

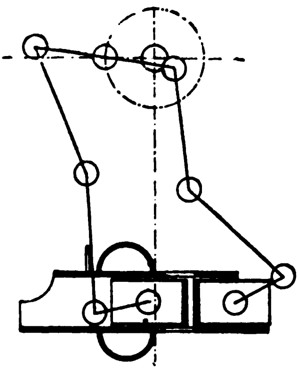


FIG. 73.—END OF EXHAUST.

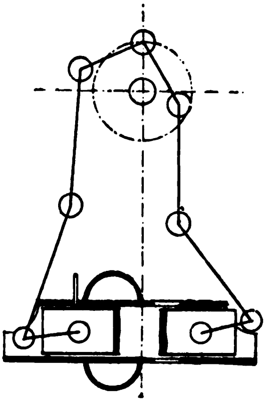


FIG. 74.—VOLUME OF CHARGE.

DIAGRAMS OF DIFFERENTIAL GAS ENGINE.

The diagrams, Figs. 73, 74, 75, 76, show the various positions of the two pistons and links of the engine at four points during one complete revolution of the main crank-shaft, and fully explain the differential motions of the two pistons.

In Fig. 73 the two pistons are close together at one end of the cylinder, all the residual products of combustion from previous charges being entirely expelled; so that in this engine a fresh start is made every revolution, and one has not to consider any burnt products left over from the previous stroke, whilst premature ignition is also prevented without requiring a scavenging charge.

During the quarter revolution from position Fig. 73 to Fig. 74 is the **suction** stroke; the pump piston P has moved rapidly away from the motor piston W, leaving a considerable space between them which is filled up with a pure combustible mixture of gas and air drawn in automatically through the self-acting suction valve A, the passage to which is represented by the open space in the black lines at the top of the cylinder. The distance between the pistons here indicates the volume for the charge of gas and air.

As soon as the crank pin moves beyond the position shown in Fig. 74, the motor piston W passes the openings to the valves, shutting the charge in between the pistons and the cylinder walls, where it is kept until after the whole work is done, clear of all passages or valves, and consequently the area of the containing surface is reduced to that of a simple cylinder.

The pistons are travelling both at the same speed and in the same direction; but about this time the motor piston W begins to travel faster, with the result of transferring the charge to the igniting end of the cylinder, and *compressing* it as the pistons approach each other, until they arrive at the position shown in Fig. 75, when the charge is compressed to any desired pressure, about 45 lb. per square inch.

At this point the charge is ignited by the pumping piston uncovering the opening to the ignition tube, which is kept red hot by a Bunsen burner. Very rapid *expansion* of the ignited charge now takes place, causing a working stroke by the motor piston, which continues until the crank pin arrives at the lowest position, as shown in Fig. 76, when the *exhaust* is allowed to take place by the motor piston passing the exhaust port, and lifting up the self-acting exhaust valve. During this working stroke the pump piston remained almost stationary, not having moved more than one-eighth of an inch, acting as a cylinder end cover, whilst the expansion has taken place to the original volume, and the pressure fallen to about 30 lb. But the expansion is continued until the space between the pistons is nearly double that into which the charge was drawn, and therefore the expansion is continued to nearly twice the original volume, when the pressure has been reduced to about 10 lb. above atmospheric. All the work done during this continued expansion is a clear gain.

From the position in Fig. 76 the pump piston follows up the other, and drives out all the products of combustion by the exhaust till the original state of things in Fig. 73 is again reached, and *the whole cycle completed in one revolution.*

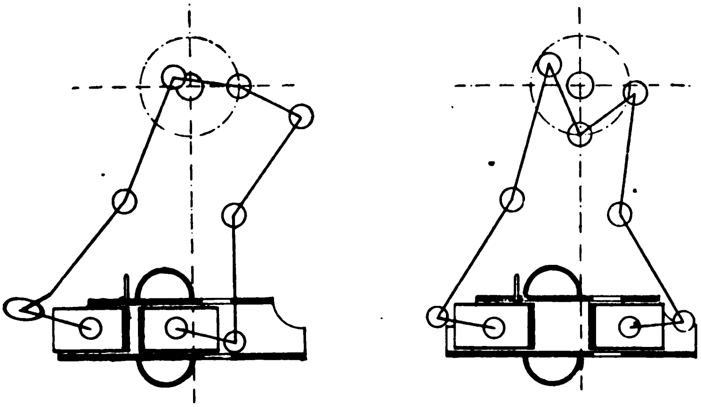


FIG. 75.—COMPRESSION VOLUME. FIG. 76.—EXPANSION VOLUME.

DIAGRAMS OF DIFFERENTIAL GAS ENGINE.

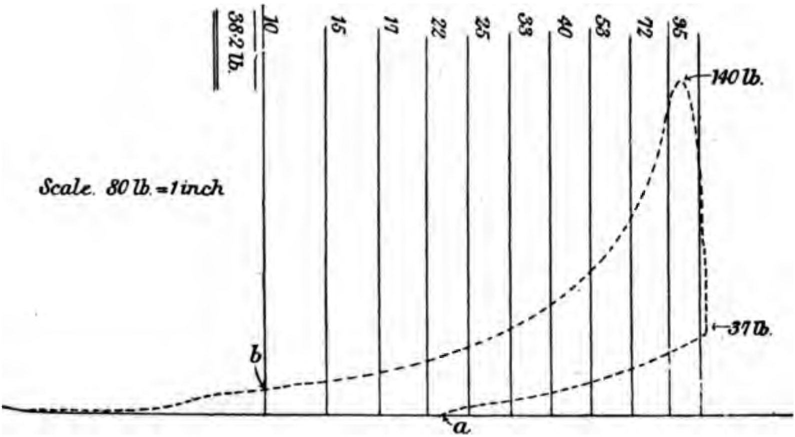
It is evident that the total expansion to twice the original volume takes place, from Fig. 75 to Fig. 76, in a quarter of a revolution, that is, in *one-fourth the time of any other engine* which expands to the original volume only in half a revolution, whereas the *Differential expands its charge to double volume in half the usual time, therefore the expansion to the original volume is done in one quarter the time,* with the same speed of engine.

Hence the work is done with four times the rapidity, or the heat has only one-quarter the time to flow away by the water-jacket, thus effecting a very great saving, for the transmission of heat through cylinder walls is directly proportional to the time that the difference of temperatures continues, as well as to the difference itself. In this way there is utilised nearly three-fourths of the heat formerly lost by that necessary evil, the water-jacket. Moreover, a great amount of work is taken out of the ignited charge by expansion to twice the original volume, the temperature and pressure of the gases being reduced accordingly; whereas, with the Otto cycle, a whole cylinder full of products at high temperature and pressure are rejected by the exhaust, and all the heat in them lost. These two obvious sources of economy were calculated to make the engine a success.

The wearing parts consist of round pins or bearings and pistons. Unfortunately there are too many pins and joints for success from a mechanical point of view. Still, calculation shows that there is not an attachment the joint of which is subjected at any time to a pressure above 10 lb. Besides, the stress on the bearings increases gradually whilst compressing the charge, so that there is no sudden blow caused by the ignition and explosion of the charge, and at the moment of highest pressure on the pistons the short connecting rods (position in Fig. 75) are most favourably placed, being tangential to the pull, any angular thrust being taken up by the round bearings. However, the links and levers were rather clumsy and gave trouble.

Trials.—In 1885 the Author tested a 2 horse-power (nominal) Differential gas engine, during a run of one hour, under ordinary working conditions; the engine had been running with the same load for half an hour previously. The useful power was measured by a simple friction brake consisting of a strap on the fly-wheel, with the load of weights on one end and a spring balance taking the slack at the other. The difference or net weight was 41·4 lb., at a mean speed of 148 revolutions per minute, the effective circumference of the fly-wheel being 14 feet. This gives effective rate of working $\frac{41 \cdot 4 \times 148 \times 14}{33{,}000} = 2 \cdot 6$ brake horse-power. The gas consumption during the hour, as indicated by a specially tested meter, was 67 cubic feet of London gas, that is, at the rate of $\frac{67}{2 \cdot 6}$ or 25·77 cubic feet per hour per brake horse-power.

The Author has notes and figures obtained in other tests of the same engine with 2·94 brake horse-power, using 24·44 feet of gas per hour per brake horse-power; also another with 2·85 brake horse-power and gas consumption 23·4 cubic feet per brake horse-power hour. These are quite sufficient to establish the superior economy of the Differential engine; in fact, so far as the Author is aware, no 2 horse-power gas engine of any other type ever before that time did a brake horse-power with so small an amount of coal gas of the same quality and at the same compression of charge.



Speed 140 revs per min. giving 6 indicated HP.

FIG. 77.—INDICATOR DIAGRAM. ATKINSON DIFFERENTIAL ENGINE.

Indicator Diagram.—It is impossible to get a complete diagram from this engine, as no part of the cylinder is open to the space between the two pistons during a complete revolution. Fig. 77 is an indicator diagram taken from a 4 horse-power nominal.

This is not a maximum diagram: it indicates 5 horse-power, taken when the engine was working very economically.

The figure does not give the pressure during the whole of one revolution, as the port to the indicator is covered part of the time by one of the pistons. It opens at *a*, just after the suction has commenced, and closes at *b*, immediately before the exhaust is opened. This diagram is taken with the stroke of the motor piston, and equal distances horizontally do not represent equal volumes between the pistons. The ordinates divide the diagram unequally, but into divisions which would represent equal volumes between the pistons.

The shape of the indicator diagram can be varied in a gas engine by *altering* the *conditions* of *working*—strength of mixture, that is, the ratio of air to gas, amount of compression, time of ignition, and speed of piston—to that which experiment proves to be most favourable for economy of gas and durability of the engine.

The richest mixture consists of 5·6 volumes of air to 1 of gas, but *8 volumes of air to 1 of ordinary coal gas is the usual strength for best economy.* This mixture can be made to burn at lower pressure than the ordinary, in fact to give the same effect as Otto's diluted mixture, by simply varying the speed of engine and the point of ignition slightly, and this without residual products or any other diluent gases to retard combustion. Experiment also shows that, *at full load, with time of ignition properly regulated, an increase in compression of charge before firing means an increase in the thermal efficiency of the engine or economy in gas consumption per brake horse-power, all other conditions being the same.*

Apart from the mechanical imperfections, we recognise in the ingenious invention of the Differential a great step in advance of all previous forms of internal combustion engine towards the conditions most favourable to economy and efficiency in small gas motors. The regenerator *seems* impracticable for engines of small power with internal combustion. *High compression* of charge before ignition has been proved to give good results. *Small surface exposure* of the cold cylinder walls, together with *rapid expansion*, very considerably reduces the amount of heat lost by conduction through the cylinder walls, so that any such loss is compensated for by

he prolonged [illegible]
up close to the [illegible]
o nearly double [illegible]
atmospheric pressure [illegible]
converts a large [illegible]
into mechanical [illegible]

[illegible]

The [illegible] — [illegible]

[illegible]

(2) rapid rate of doing work, (3) great range of expansion, (4) great control by centres and novel yet simple linkwork. The peculiarity of the **Cycle Engine** is that a single piston performs the whole Beau de Rochas cycle of operations—charging, compression, expansion and exhaust—in four strokes of unequal length in the one cylinder during a single revolution of the crank-shaft. We have seen that in the Otto engine the cycle is only completed in two revolutions of the crank-shaft, the one cylinder being used for the charging, compression, expansion and exhaust strokes. In order to have an impulse or working stroke every revolution, it is common to employ a separate pump cylinder for mixing and compressing the charge before admitting it into the working cylinder. This secures greater regularity of speed, but necessarily increases the consumption of fuel per horse-power, since the friction is increased, and the work done by the separate pump has to be deducted from that obtained in the working cylinder. It is now generally considered most desirable from an economical point of view to clear out of the cylinder all the burnt products from previous combustions by a scavenger charge of air before introducing the *cool* explosive mixture; and some engines of the six-stroke cycle type actually sacrifice a revolution for the purpose.

Such difficulties are overcome by Atkinson in the Cycle engine, which is of novel, peculiar and simple design, realising exceptional economy and regularity of speed with satisfactory performance in practice.

The general arrangement of the Cycle engine is shown in Fig. 79. The connecting rod is not directly joined to the crank, but through a toggle link and rocking lever. The piston is fixed to the link at a point some distance from the toggle joint. Hence the initial explosion pressure on the piston does not come directly on the crank shaft, but is transmitted to the centre of this toggle lever, which oscillates on a large bearing lined with white metal across the whole base of the engine. Then the peculiar link motion gives a very uniform turning moment on the crank pin during the first four-fifths of the working stroke. The maximum pressure on the crank pin and main bearings never exceeds 35 per cent. of the maximum initial pressure. This greatly reduces friction, wear and tear of the crank pin and main journals, and, in conjunction with the impulse every revolution, contributes to the remarkable regularity of speed of the engine running under widely varying loads. Thus, when the full load is suddenly thrown off there is only a very slight variation in speed, amounting to about 1·75 per cent. of the minimum speed at which the engine was running with full load.

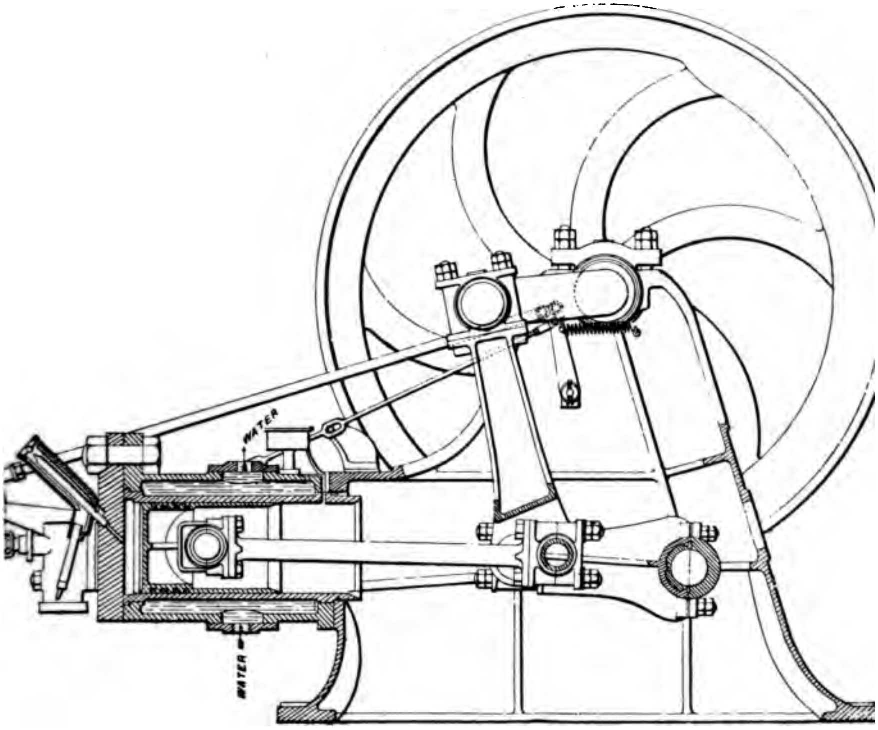


FIG. 79.—THE ATKINSON CYCLE GAS ENGINE (LONGITUDINAL SECTION).

By means of this linkwork the piston makes two double strokes, all of unequal length, for each revolution of the crank-shaft. In a revolution of the crank-shaft, starting from the extreme end of the cylinder, as in Fig. 79, the piston in a compression and range of expansion. *Only experience can determine the best conditions of working with different qualities of gas under certain circumstances.* Various kinds of cheap fuel gas, Dowson gas, and Mond gas can be used as the fuel and working agent in the Cycle engine, giving uniform steadiness of running with exceptionally good economy in comparison with other heat engines in ordinary use.

In the 8 horse-power and larger sizes, the crank shaft and fly-wheel are placed below for greater stability, and the toggle lever oscillates about the bearing across the top of the frame, as seen in Fig. 82, which, with the longitudinal section, Fig. 83, clearly shows the main features in the design.

From the mechanical point of view, the transmission of the working force from the piston through the connecting rod, toggle lever and link to the crank, contrasts unfavourably with the simple direct method by the ordinary connecting rod and crank. There are too many joints and moving parts, including the linkwork, which make the engine costly to build, and with the very high piston speed increases the wear and tear. The linkage is not suitable for balancing in large engines. These difficulties prevented the commercial success of the engine.

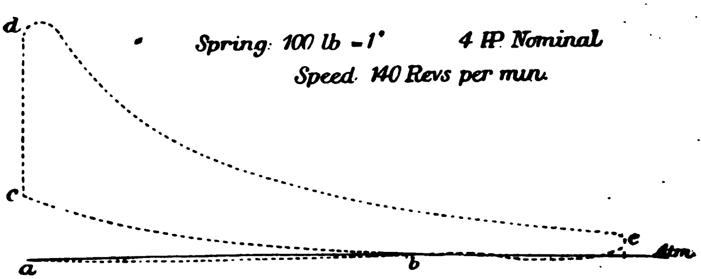


FIG. 81.—INDICATOR DIAGRAM. ATKINSON CYCLE GAS ENGINE.

Until the year 1893, over 1000 Cycle engines were built and sold by the British Gas Engine Company, Gospel Oak, London. The Cycle engine was also made in Philadelphia, United States ; and in this country Messrs. Manlove, Alliott and Co., of Nottingham, commenced in 1889, and till 1892 built a considerable number in sizes giving 2 up to 30 effective horse-power when running at 180 to 110 revolutions per minute.

The Cycle engine is fitted with an *air suction pipe*, 14 to 20 feet long, adjusted to prevent back-firing therein, by scavenging the residual burnt gases. For this purpose there is special *valve setting*. In a 10 horse-power nominal or 16 brake horse-power engine running at 110 revolutions per minute, the air-admission or suction valve is set to open at ½ an inch travel of piston before the end of exhaust stroke, and only closes when the piston has travelled ½ inch on the compression stroke. The exhaust valve opens at 1¾ inch travel of piston before the end of working stroke to give release, and closes when the piston has travelled ¾ inch on the suction stroke. This arrangement

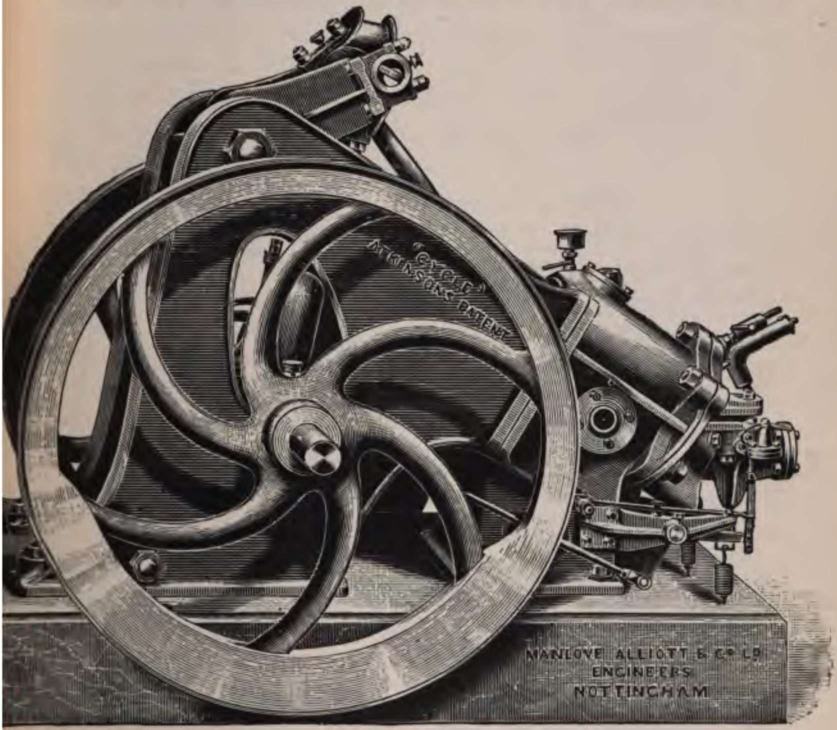


FIG. 82.—10 HORSE-POWER ATKINSON CYCLE GAS ENGINE.

gives best working results at the given speed with an air pipe of 3 inches bore and about 14 feet in length. A change of a few feet in the length of the suction pipe alters the horse-power of the engine.

When the burnt gases are swept clean into the exhaust by means of pure air, a greater weight of fresh charge can be introduced into the cylinder, giving greater power.

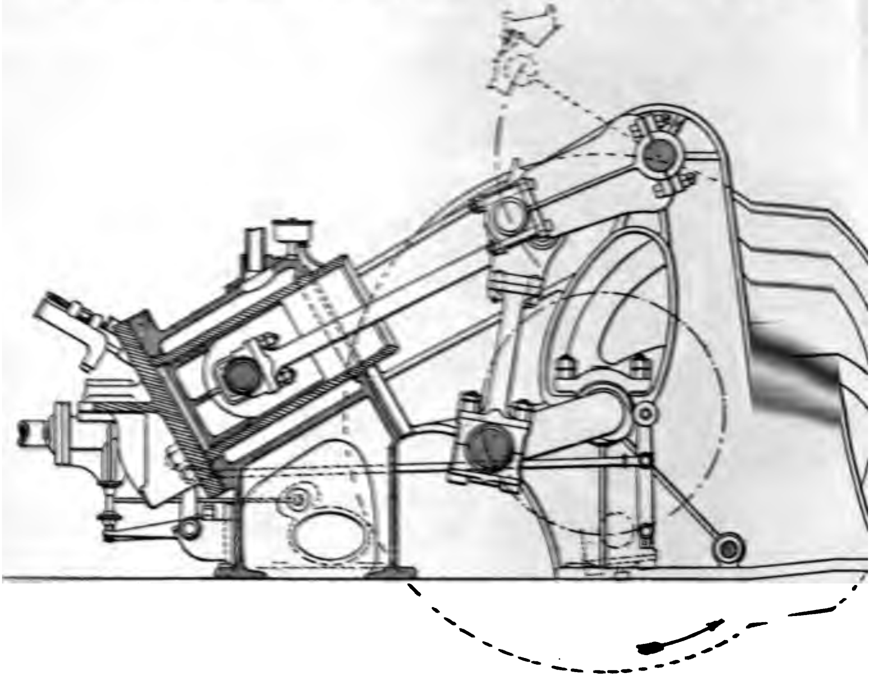


FIG. 83.—10 HORSE-POWER ATKINSON CYCLE GAS ENGINE (LONGITUDINAL SECTION).

Experiment also shows that the rate of consumption of gas per brake horse-power hour, is reduced fully 10 per cent. by scavenging.

The speed in the 10 horse-power Cycle engine can be altered from 80 to 90 or 120 revolutions per minute, by tightening or slackening the spring on the horizontal centrifugal -nor to suit convenience. When the speed is too high the governor moves the rod aside to miss the gas valve spindle, and so prevents admission of charge until the speed is reduced to the normal.

Trials.—In the year 1890, a 2 horse-power Cycle engine, cylinder $6\frac{1}{4}$ inches diameter and working stroke $8\frac{5}{16}$ inches, supplied by Messrs. Manlove, Alliott and Co. to the University College, Nottingham, was tested by the Author, and gave 3 brake horse-power at 150 revolutions per minute, with a gas consumption of 60 cubic feet per hour, or at the rate of 20 cubic feet per brake horse-power hour, not including the gas for the ignition, which was about 4 cubic feet per hour. The actual heating value of the town gas used, in the engine cylinder, was 600 B.Th.U. per cubic foot. Only once during ten years has the bearing of the vibrating lever needed attention, and except the renewal of ignition tubes the engine has required no repairs and the valves were never ground on their seats; the engine is still working steadily about fifteen hours a week, though the cylinder liner is worn. Mr. H. B. Ransom found the cyclical velocity variation, measured by his speed recorder,[*] was exceptionally low in this engine—only 3 per cent. at half load. The results recorded agreed closely with calculation depending on the speed, inertia of fly-wheels and reciprocating parts, and the indicator diagram.

The first Cycle engine constructed was tested by Professor Unwin in 1887, and gave 4·89 brake horse-power, with a consumption of London gas at the rate of 22·5 cubic feet per brake horse-power hour. The thermal efficiency was 20·6 per cent. of the heat of combustion indicated or turned into work done on the piston. The ratio of expansion was 1 ÷ 3·75, that is, if the volume of the compression space be taken as 1, then the volume swept by the piston during explosion and expansion of the charge is 2·75, so that the gases compressed before ignition into one volume are allowed to expand to 3·75 times that volume during the working stroke. In the 4 horse-power Otto tested by Dr. Slaby, the ratio of expansion was 2·7 (see page 112).

In the 6 horse-power nominal Cycle engine tested at the

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[*] See [illegible] C.E. vol. xcviii. p. 357, and vol. cix. p. 330.

Society of Arts, the length of strokes are given above, page 152. The principal results are given in the table as follows:—

TRIALS OF ATKINSON CYCLE ENGINE (Society of Arts, London, 1888).

Date	September 21	September 22	September 22
Duration of trial	6 hours	3 hours	½ hour
Power	full	half	empty
Revolutions per minute	131·1	129·6	131·9
Explosions per minute	121·6	69·1	23·8
Pressure before ignition (absolute)	50·3	..	..
Explosion pressure (absolute)	180·9 lb.	166·5 lb.	145·5
Mean effective pressure	46·07 lb.	47·6 ,,	48·59
Indicated horse-power	11·15	6·59	2·3
Brake horse-power	9·48	4·74	..
Mechanical efficiency	85 per cent.	71·9 per cent.	..
Indicated horse-power spent in driving engine alone	1·67	1·85	..
Gas used per hour (main), cub. ft.	209·8	127·1	47·2
,, ,, (ignition) ,,	4·5	5·9	..
,, ,, (total) ,,	214·3	133·0	..
Gas per I.H.P.-hour (main ,,	18·82	19·29	20·5
,, ,, (total) ,,	19·22	20·18	..
Gas per brake H.P.-hour (total)	22·61	28·1	..
Heating value of gas, B.Th.U. per cub. ft. (calculated from analysis)	633	..	..
Cooling water per hour	680 lb.	260 lb.	..
Rise of temperature of water	50° F.	67°·8 F.	..
Thermal efficiency:—			
Heat turned into work indicated in the cylinder	22·8 per cent.	22·3 per cent.	21 per cent.
Heat lost by water jacket	27 ,,	23·2 ,,	..

The engine worked very satisfactorily, and gave the lowest consumption of gas in this competition. Compare results of the Crossley engine, page 127. Owing to the low pressure reached at the end of the expansion the exhaust was comparatively quiet. In the speed trials the greatest variation in speed with full load and running light was from 128·5 to 130·75 revolutions per minute, that is only 1·75 per cent

In 1891, at the Uxbridge Waterworks, Mr. J. Tomlinson made careful tests of a pumping plant, consisting of 15 horse-power nominal Cycle gas engines coupled direct to double-acting pumps, and driven by Dowson gas. Compressed air was used to start the gas engines. The diameter of the cylinder was 14 inches, the working stroke 14·19 inches, and at the usual speed of 110 revolutions per minute would give 27 brake horse-power with town gas. During a six hours' run the average speed of the engine suitable for the pumps was 86 revolutions per minute, and the engine was only giving out 16·7 indicated horse-power and the pumps 12 effective horse-power in water raised. In six hours the fuel used was 88 lb. anthracite and 19 lb. of coke, making a total of 107 lb., that is, 17·83 lb. of fuel per hour. The consumption of fuel is at the rate of 1·06 lb. per indicated horse-power hour, and 1·49 lb. per effective horse-power in water raised and delivered by the pumps. These results were verified, and show a remarkably low consumption of fuel, better than the most economical results obtained from a good large condensing steam engine and boiler, which require 1·5 lb. of coal per indicated horse-power hour, and 1·75 lb. per effective horse-power hour; whilst large pumping engines work with over 2 lb. of coal per effective or pump horse-power hour on a test, and use about 3 lb. or 4 lb. per effective horse-power hour in ordinary working.

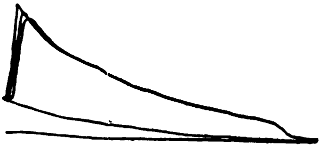

FIG. 84—Indicator Diagram. Scale of Spring, 1″ = 150 lb.; Mean Pressure = 55·4 lb.; Speed, 250 revs. per min.

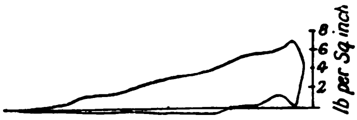

FIG. 85.—Pump Diagram. Mean Pressure = 2·9 lb. per square inch.

ATKINSON UTILITÉ GAS ENGINE (1892).

The **Utilité**.—The *Utilité* gas engine, invented by Mr. Atkinson, has a trunk piston working in the motor cylinder and joined by a connecting rod to the crank shaft. The front end of the cylinder is enclosed, and that side of the motor piston acts as a pump drawing in and compressing air to 5 or 7 lb. per square inch. There is an automatic inlet valve between the air chamber and working end of the cylinder, so that the charge of pure air under slight pressure rushes into the motor cylinder after the motor side of the piston uncovers the exhaust part at the close of the working stroke, clearing the burnt gases out of the cylinder. A separate pump, worked by an eccentric on the crank-shaft, draws in a rich mixture of gas and very little air, and delivers it into the combustion chamber in back end of the motor cylinder, just as the motor piston in its return stroke covers the exhaust port and begins to compress the air. By this device a rich explosive mixture is formed in the cylinder, and by proportioning the pump and motor cylinders the charge, when fired, can be allowed to expand beyond the volume occupied before compression.

The indicator diagrams, Figs. 84 and 85, taken from the motor cylinder and pump, show the pressure in one of the first Utilité engines, built in March 1892. An impulse every revolution was obtained with the pump scavenging by means of air. Only a few Utilité engines were built when the British Gas Engine Company gave up business early in 1893; Mr. Atkinson joined the firm of Messrs. Crossley Brothers, and the manufacture of the Atkinson engines ceased.

CHAPTER VII.

SIX-STROKE CYCLE GAS ENGINES.

Linford.—A new cycle of operations in the gas engine, nvented by CHARLES LINFORD, patent No. 330 of 1880, has for its sole object to clear the cylinder and passages of any residual burnt gases from the previous explosion, by drawing into the cylinder, during one stroke, and discharging through the exhaust, by the return stroke, a *scavenger* charge of fresh air, before taking in each charge of explosive mixture to be dealt with as in the Beau de Rochas cycle. The omplete cycle of operations is performed by six strokes of iston as follows: (1) drawing in the charge of gas and r; (2) compression of the charge of gas and air; (3) ignition, mbustion and expansion; (4) exhaust, expelling the products combustion; (5) drawing in a scavenger charge of air only;) expelling the scavenger charge of air mixed with residual rnt gases. Single-acting engines on the Linford cycle have ly one explosion to every three revolutions of the crank-aft; and in double-acting engines, two explosions to three volutions. On this account it is also known as the *three-le* type, although really the *three revolution cycle.*

The first practical use of this scavenger arrangement pears to be in the Linford vertical gas engine, shown in g. 86, brought out early in 1880. The charge of gas and is admitted between two pistons working in opposite rections in the cylinder. The return stroke compresses e charge. The explosion then takes place between the o pistons, forcing one upwards and the other downwards. he impulse is transmitted by rocking levers to the cranks, hich being in opposite directions avoid shock on the crank-aft. Hence it was called the "automatic" balanced gas motor. After the explosion and exhaust strokes a "scavenger" charge of air alone is drawn into the cylinder and discharged through the exhaust pipe. The engine was necessarily bulky for the power, with only one working stroke in six.

A large fly-wheel would be required to give steady running. A governor controlled the supply of gas to regulate the speed. In the year 1880 this vertical engine was built by Messrs. C. Linford and Company, of Leicester, in sizes of 1 to 5 effective horse-power at speeds of 140 to 200 revolutions per minute.

Subsequently Linford patented improvements in his horizontal engine, which promised to be a formidable rival to the Otto, when the decision against Linford, and in favour of Otto's patent, in the Court of Appeal was a great blow to the gas engine industry in this country.

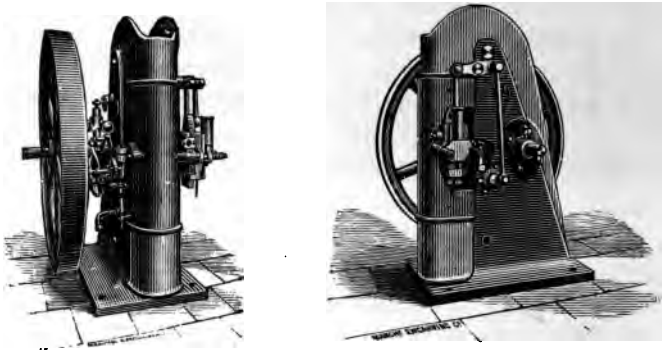

FIG. 86.—LINFORD GAS ENGINE.

Rollason's Beck Engine.—The next successful gas engine brought out on the Linford cycle was the Beck, patented in 1886 by Mr. ARTHUR ROLLASON, and built by the Beck Gas Engine Company, of Newcastle-on-Tyne. The Beck is single-acting, of the six-stroke cycle type, taking in and discharging a "scavenger" charge of air, during two strokes of the working piston, before drawing in each charge of explosive mixture, as in the Otto engine. At all ordinary powers, except when running light, there is one explosion to every three revolutions of the crank-shaft, under all circumstances. The governor controls the speed by throttling the gas admission, and only when the engine is running light or at very small load does the governor completely cut off the gas. The governor is so arranged that by shifting a small balance weight on a lever, which can be done by hand without stopping the engine, the steady speed may be altered from 150 to 200 revolutions per minute to suit the load. A slide valve is used for admission and ignition of the charge. A special feature of the Beck engine is the hollow jacket or air space around the combustion chamber, between the latter and the water-jacket. This air-jacket prevents or reduces the loss of the intense heat in the combustion chamber by radiation, and conduction to the water-jacket.

Trials.—A thorough scientific test of a small Beck gas engine was made by Professor A. B. W. Kennedy, F.R.S., in February 1888. Careful measurements were made of the indicated and brake power, speed, gas consumption and jacket water, and a heat account drawn up for each experiment. The engine had been supplied to the Joel Electric Lighting Company, to drive machinery in their workshop at Finsbury, where the trials were carried out. The engine was of 4 horse-power nominal, with cylinder 7·55 inches diameter and 15·02 inches stroke, intended to run equally well at any speed from 150 to 200 revolutions per minute. Every precaution was taken to ensure strict accuracy in the observations—the measuring instruments being calibrated and the adjustments checked. Two experiments, A and B, were made at full power, and speed about 210 revolutions per minute; two more, C and D, at a lower speed, about 165 revolutions per minute, one at the greatest load for that speed, and one somewhat throttled; another, E, at 180 revolutions per minute and maximum load; and the sixth, F, with the engine running light:—

A,	2½	hours' run,	206	revolutions	per minute,	8	I H.P. and	6·3	B H.P.
B,	1	,,	212	,,	,,	7·3	,,	5·7	,,
C,	2½	,,	163	,,	,,	6·9	,,	5·8	,,
D,	2	,,	169	,,	,,	6·1	,,	4·8	,,
E,	½	,,	184	,,	,,	—	,,	6·5	,,
F,	¼	,,	222	,,	,,	empty			

The last four, C, D, E, F, were made continuously, without stopping the engine or taking off the load; this was changed, and the governor altered for the new speed, without any pause in the running of the engine, which was working continuously under test for seven hours that day.

The governor control, by throttling in all the experiments, was perfect, and, kept the same steadiness at all speeds. There were no explosions cut out, no miss-fires and no back ignitions whatever. Over the range of the four experiments, A, B, C, D, the engine worked with uniform steadiness, and with practically the same economy, the mean consumption of gas being 21·42 cubic feet per indicated horse-power, and 26·79 cubic feet per brake horse-power per hour. The greatest economy was 20·67 cubic feet per indicated horse-power hour, which was a very good result for an engine of that size.

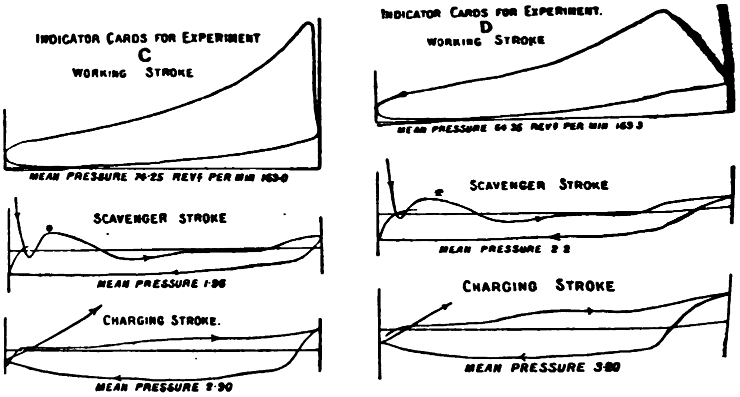

FIG. 87.—INDICATOR DIAGRAMS. BECK ENGINE.

The heating value of the coal gas, calculated from analysis, was 611·4* B.Th.U. per cubic foot through meter. The most economical results were got with the most dilute charges, in which the ratio of gas to air was about 1 to 11·8 by volume and 1 to 31·5 by weight.

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* Professor Kennedy pointed out that after the heat account was compiled, the calorific values given for the marsh gas and the olefines include the latent heat of the steam formed in the combustion. In the gas engine, the water formed by combustion passes away as steam gas, and the corrected calorific value for the coal gas gives 585 B.Th.U. per cubic foot; the thermal efficiency is increased to 21·1 per cent. of heat converted into work.

The principal results of two experiments are as follows:—

TRIALS OF ROLLASON'S BECK GAS ENGINE: London, 1888.

Experiment	C.	D.
Date	February 25	February 25
Duration of trial	2·5 hours	2 hours
Revolutions per minute	165·2	188·0
Explosions per minute	54·38	56·27
Pressure before ignition (absolute) . .	56·4 lb.	50·5
Explosion pressure (absolute) . . .	210·0 "	158·7 lb.
Mean pressure during working stroke . .	74·61 "	65·08 "
Mean pressure during pumping stroke. .	5·00 "	5·14 "
Mean effective pressure, nett . . .	69·61 "	58·84 "
Indicated H.P., working stroke . . .	6·88	6·12
" **nett.**	6·42	5·62
Brake horse-power	5·85	4·84
Mechanical efficiency	90·8 per cent.	86·1 per cent.
Gas used per hour, cubic feet . . .	152·4	126·5
Gas per nett indicated H.P. hour, cubic feet	22·15	20·67
" **brake H.P. hour, cubic feet** .	26·10	26·14
Ratio of gas to air by volume . . .	1/9·13	1/11·8
Heating value of gas, B.Th.U. per cubic foot	611	611
Cooling jacket water, lb. per hour . .	380	330
Rise of temperature of water . . .	86° F.	74°·0 F.
Thermal efficiency:—		
Heat turned into indicated work . .	19·0	20·2
Heat lost by jacket water	35·0	32·0
Heat lost by exhaust	38·1	45·1
Heat in scavenger charge and unaccounted for	7·9	2·7

The two sets of indicator diagrams with springs $\frac{1}{10}$, Fig. 87, clearly show the action in the cylinder during the various operations. The pumping and scavenging strokes, with a light spring $\frac{1}{8}$, are taken separately for clearness sake. These give the work done in pushing out the burnt gases, as well as afterwards the blank scavenger charge of air. The wave at the part of curve marked ∗ just after release may be due to vibration of the indicator spring.

For the purposes of calculation the simplified or ideal diagrams are plotted as in Fig. 88. The dotted lines are the actual mean diagrams determined by measurements of the actual pressures in all the indicator diagrams. The ideal diagrams agree closely with the real ones, except the rounding of corners. The whole volume of the cylinder is 0·579 cubic foot. The compression volume is 0·19 cubic foot, and the volume swept by the piston 0·388 cubic foot, so that the ratio of expansion is nearly 3. It is impossible for the whole of the products to be swept out, because the scavenger charge of air drawn in mixes with half its volume of products of combustion, and then only two-thirds of this mixture is again expelled, leaving the remaining third in the clearance space.

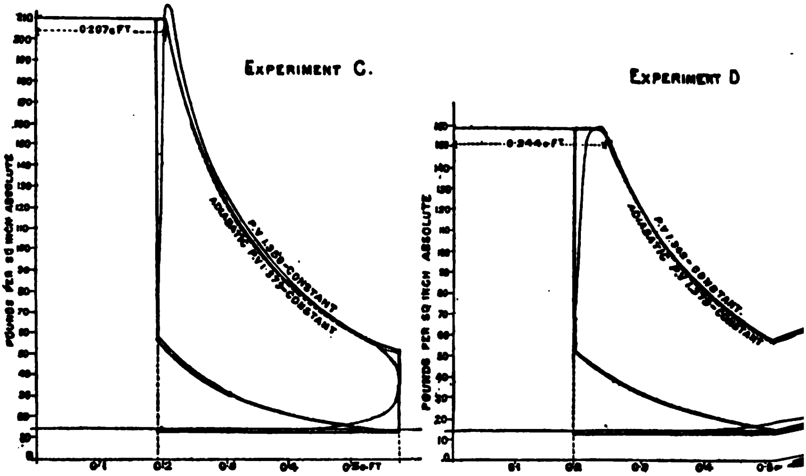


FIG. 88.—IDEAL DIAGRAMS. BECK ENGINE.

The Beck trials can be compared with those conducted by the Society of Arts on the same lines later in the year, and reported on by Professor Kennedy.

Chiefly owing to the number of idle strokes in this cycle, a comparatively large single-acting engine was required for a given power, and could not compete in price with the four-stroke cycle, to which these gave place on the expiry of the Otto master-patent.

The six-stroke cycle is best adapted to double-acting engines, and this is taken advantage of in the Griffin engine, which came out about the same time.

Griffin Gas Engine.—Mr. SAMUEL GRIFFIN, of Bath, patented a gas engine which affords a striking example of the many variations possible in the order of operations in the cylinder of the internal combustion engine. This early form of the Griffin engine, Fig. 89, is of the six-stroke cycle type, converted into the *three-cycle type* by being made double-acting. The cylinder is closed at both ends, Fig. 90. The charge of gas and air is fired alternately on each side of the piston once every three revolutions, and thus gives one impulse to the piston every one and a half turns of the crank-shaft, with a cooling and cleansing or scavenger charge of air coming between each explosion.

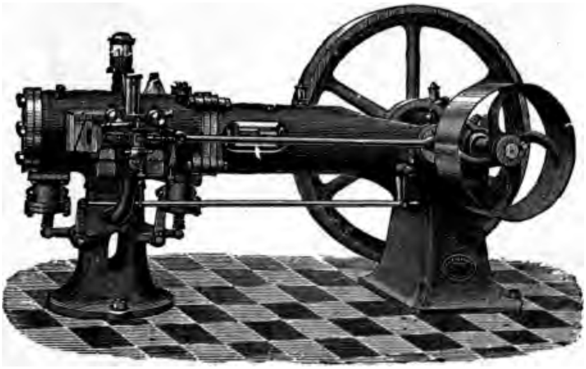
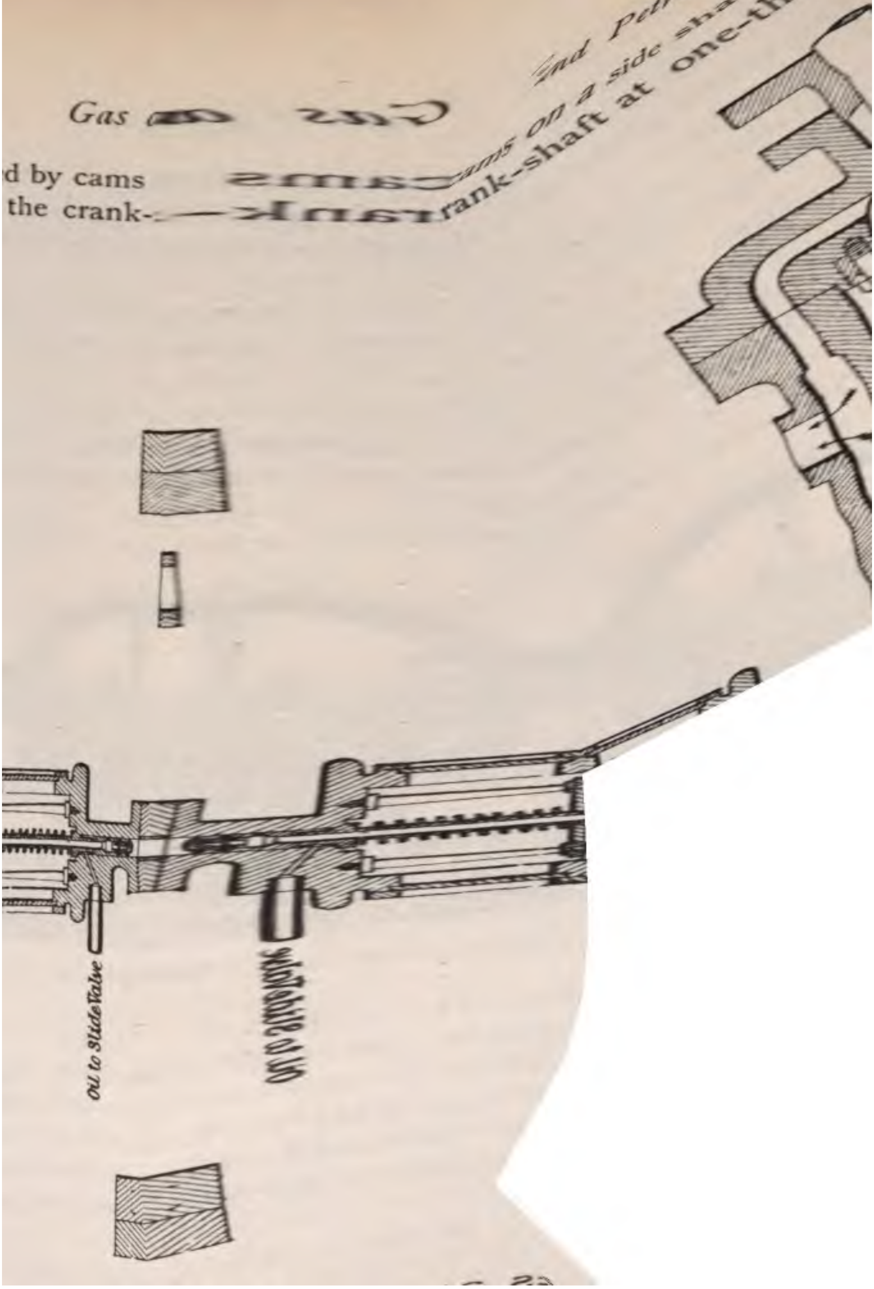


FIG. 89.—EARLY GRIFFIN DOUBLE-ACTING ENGINE.

The *ignition* is by flame and plain slide valve with a small chamber containing gas under pressure.

The air is admitted by the opening and pipe seen in the base. The admission and exhaust valves are disks of the conical-seated lift type, held on their seats by spiral springs,

d by cams on a side shaft, which
the crank-shaft at one-third s



The *water-jacket* around the piston-rod stuffing-box is essary to prevent overheating. This rod has to pass

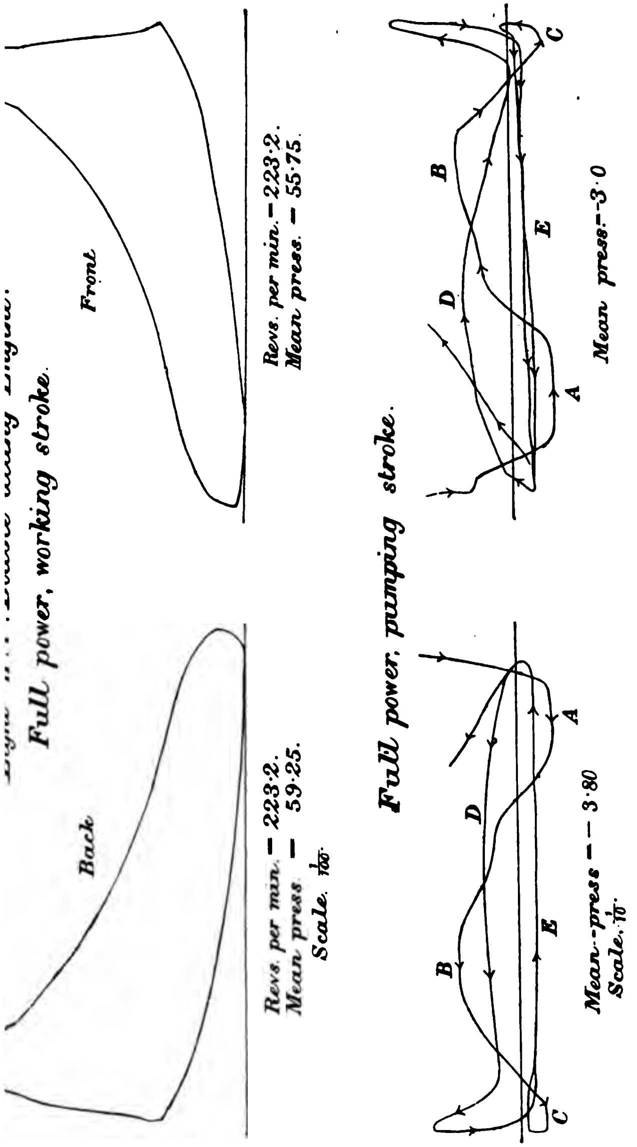


FIG. 91.—INDICATOR DIAGRAMS. GRIFFIN DOUBLE-ACTING GAS ENGINE.

through a burning charge in the front end of the cylinder, the temperature of which is not less than 1400° to 1600° Centigrade. This would speedily raise the temperature of the rod so as to destroy all lubrication and packing. But, whilst the water-jacket is effective in preventing overheating even during a long run, the cooling surface of the rod unfortunately reduces the mean effective pressure during combustion in the front end of the cylinder. In the motor trials by the Society of Arts in 1888, the mean effective pressure in the front end of the cylinder in the Griffin engine was from 6 lb. to 14 lb. lower than in the back, doubtless in a great measure due to the influence of this extra cooling surface of the piston rod and end cover jacket.

Whenever the engine is running over speed the *centrifugal governor* completely cuts off the admission of gas, causing one or more explosions to be missed until the speed is reduced to its normal value, about 200 revolutions per minute.

The cycle of the Griffin double-acting engine may be seen by the two sets of *indicator diagrams*, Fig. 91, taken from both ends of the cylinder.

The order of operations at each end of the cylinder is as follows: Drawing in the combustible mixture of gas and air, compressing this charge, ignition and explosion, ejecting the products of combustion, drawing in a scavenger charge of air, and ejecting this scavenger charge of air.

In Fig. 91 the compression and explosion strokes are given, as well as the small variation in pressure during A B *exhaust* of residual products, C suction, and D sweeping out *scavenger* air, and E *suction* of combustible charge at a pressure of 1 lb. per square inch below atmosphere. These two pumping strokes represent work done *on* the gas *by* the engine, and the mean back pressure 3·54 lb. per square inch must be deducted from the mean pressure during working stroke to give the mean effective pressure exerted *by* the gas *on* the piston.

Trials.—At Kilmarnock, in November 1887, Professor Jamieson tested an 8 horse-power nominal Griffin engine having a cylinder 9 inches diameter, and stroke 14 inches.

The clearance space was 45 per cent. of the volume swept by the piston. At 183 revolutions per minute the engine indicated 17·28 horse-power, and gave 13·6 brake horse-power with 24·48 cubic feet of gas per brake horse-power hour. The heating value of the gas, from analysis, was 639 B.Th.U. per cubic foot, so that the engine gave a thermal efficiency of 20·8 per cent. heat converted into indicated work.

The indicator diagrams, Fig. 91, were taken by Professor

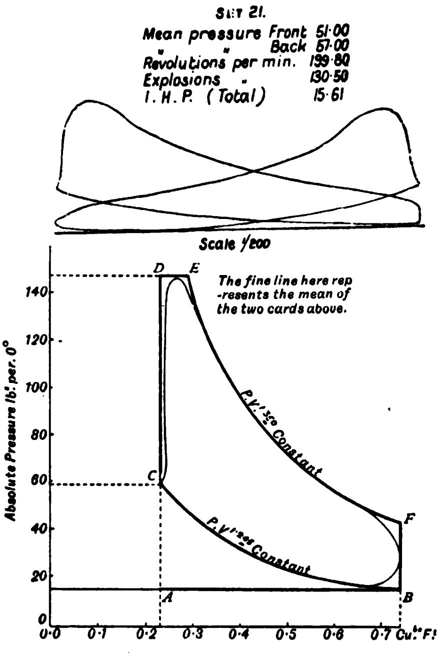


FIG. 92.—INDICATOR DIAGRAMS. GRIFFIN ENGINE.

Kennedy in a series of trials at Kilmarnock, in which he found the gas consumption at full power 23·6 cubic feet per brake horse-power per hour with rich gas.

At the trials of the Society of Arts this engine at full load had a total consumption, including gas for ignition, 28·5 cubic feet per brake horse-power per hour. The pressure may be seen from the diagrams, Fig. 92. The brake was 12·51 horse-power, and mechanical efficiency 81 per cent.

This engine ran very steadily, giving only 2 per cent. variation in speed with full load and light. In this respect it was better than the Crossley engine.

The *Griffin Twin Engine* had two single-acting cylinders side by side, and worked with this particular cycle. Since each cylinder had one explosion every three revolutions, the two cylinders gave an explosion every one and a half revolution, so that, when the cranks were set half a revolution (180°) apart, the impulses alternated in each cylinder at equal intervals. The admission of gas to the two cylinders, and the ignition, were effected by one slide valve, the two exhaust valves being opened by one cam.

There was also, for small powers, a single-acting *vertical type*, of very simple construction, with one working stroke in six. This handy little engine ran quietly, though not with the same uniformity in speed as the other types of Griffin engine. The three-cycle Griffin engine was constructed in large numbers until recently by Messrs. Dick, Kerr and Company, of Kilmarnock.

Forward Engine.—From the year 1881 Messrs. T. B. BARKER AND COMPANY, of Birmingham, built a low-pressure atmospheric engine called the Universal gas engine, of neat horizontal design, in eight sizes from $\frac{1}{8}$ to 2 horse-power. A large number of these engines were sold, but it was soon found that an engine of this construction could never compete with the compression type of gas engine.

In 1888 this firm introduced the six-stroke or *three-cycle* Forward gas engine, with one explosion for every three revolutions. The special feature of this engine was the *rotary ignition valve*, which performed all the functions of a slide valve, with the great advantage that it always moved in one direction, and wore itself down to a face instead of wearing itself out. It was a rotating disk, with a series of slide ports acting on the same principle as the reciprocating slide. For ignition a slot in the disk came across the touch-hole, and the pilot light fired the charge. An ingenious trip action, controlled by the governor, worked the disk, so that when no gas was admitted the disk did not move at all.

Very careful tests were made on the three-cycle Forward engine by Professor Robert H. Smith, at Birmingham, in May and June 1888. The piston diameter was 7·026 inches with 15·1 inches stroke, and compression of charge 48 to 51 lb. per square inch, with a mean effective pressure of 66·59 lb. per square inch, and at 176·85 revolutions per minute 58·95 explosions per minute gave 4·81 brake horse-power on a consumption of 23·97 cubic feet of coal gas per brake horse-power hour, not including ignition gas, which was burned at 1·574 cubic feet per hour. The mechanical efficiency was 85·8 per cent. The mean pressure during the pumping strokes was about 3·75 lb. per square inch. At a speed of 180 revolutions per minute, of which 120 are charging and scavenging revolutions, the power spent in pumping strokes was only ⅔ of a horse-power. Taking the calorific value of the Birmingham gas at 639 B.Th.U. per cubic foot, the thermal efficiency is 19·2 per cent. of heat converted into total indicated work. At half load, 177 revolutions per minute and 57·78 explosions per minute, the mean pressure varied from 45·6 to 65·5 lb. per square inch, and the engine gave 3·084 brake horse-power on a consumption of 31·86 cubic feet per British horse-power hour, not including ignition gas, 1·944 cubic feet per hour.

Speed tests were also made on this three-cycle "Forward" engine by Mr. Holroyd-Smith, on the 22nd June, 1888. The Prony brake used for loading the engine was so arranged that when running at full power the load could be instantly thrown off. The revolutions were counted for ten seconds with load on and noted, also for the ten seconds after the load was thrown off. This severe test was repeated eight times, while the load was suddenly put on and thrown off, and the average variation of speed between no load and full load did not exceed 2 per cent. This steadiness of running is extraordinary for an engine giving only one explosion every three revolutions. Professor R. H. Smith found that the speed kept steady for a given load, but altered with the load, running light at 180, and with full load 165 revolutions per minute.

The modern Forward gas engine is an improved Otto (see page 264).

Modern Griffin Gas Engine.—Messrs. DICK, KERR and Company also adopted the Otto cycle and built large engines double-acting, under Hartley and Kerr's system, like the Griffin engine with ends closed, having the Otto cycle of operations on each side of the piston, but without the scavenger charge to sweep out and cool the passages.

Fig. 93 has a double-acting single cylinder with the ends closed. All the valves are of the vertical lift type, worked from the side shaft which is driven by worm gear. Ignition is by hot tubes. The water-jacket surrounds the cylinder as in Fig. 90, but more cooling water must circulate to prevent overheating of the cylinder and piston, since part of the hot residual gases are left in the clearance space at each end of the cylinder. The lubrication of the piston is also made more difficult, and sight-feed lubricators are used. The oil drops into a small cup, open at the bottom to a small valve which is sucked open during the charging stroke of the piston, and the oil passes into the cylinder. A light spring keeps the valve up to a face.

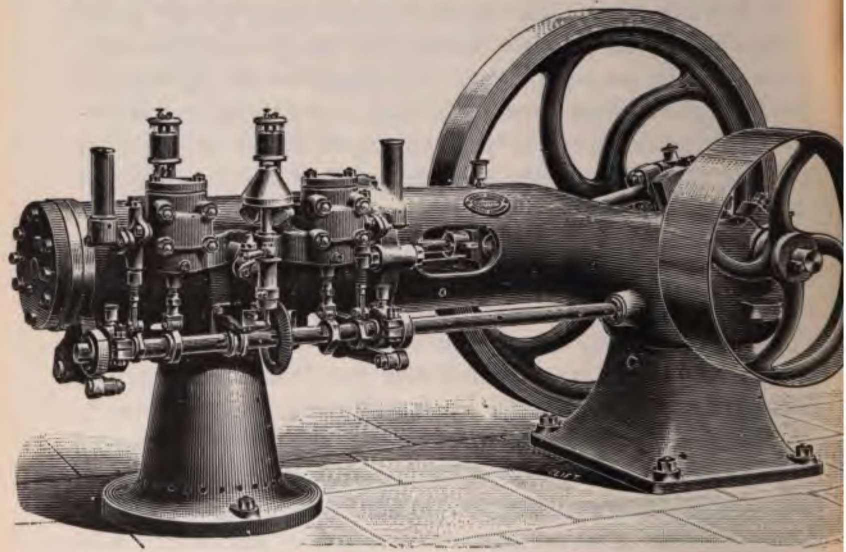


FIG. 93.—MODERN DOUBLE-ACTING GRIFFIN GAS ENGINE.

The governor worked by bevel wheels on the side shaft acts, not by cutting off the supply of gas altogether, but by throttling or gradually reducing the gas in each charge to suit the load, so that the engine works until about one-third of full load without missing an explosion. The object is to give regularity of speed. This method of governing is said to give good results in America with rich natural gas, but in this country it has been proved to greatly increase the consumption of gas, and is likely to cause other troubles of ignition when a large proportion of inert constituents are present in cheap fuel gas. The very dilute charges are difficult to ignite, burn slowly, and the combustion is sometimes incomplete at the end of the stroke. Then the hot residual gases which are not quite burnt out are apt to ignite the fresh incoming charge, causing back-firing or "back-explosions" in the air chamber, or else they may cause premature ignition of the charge during compression, and the engine will suffer in both mechanical and thermal efficiency.

In a single-cylinder double-acting engine the Otto cycle of operations is as follows :—

Direction of Stroke.	Back of Piston.	Front of Piston—crank end.	
←	exhaust	charging	1 revolution
→	charging	compression	
←	compression	*explosion*	1 revolution
→	*explosion*	exhaust	

The double shot or two explosions come one after the other in one revolution, and there are none during the next revolution. This arrangement cannot, therefore, give an explosion every revolution. When explosions are missed the action is irregular.

A great improvement is introduced in the steadiness of running by two double-acting cylinders, ends closed, working tandem, having the pistons on the same rod and connected through a cross-head and connecting rod to the crank, Fig. 94.

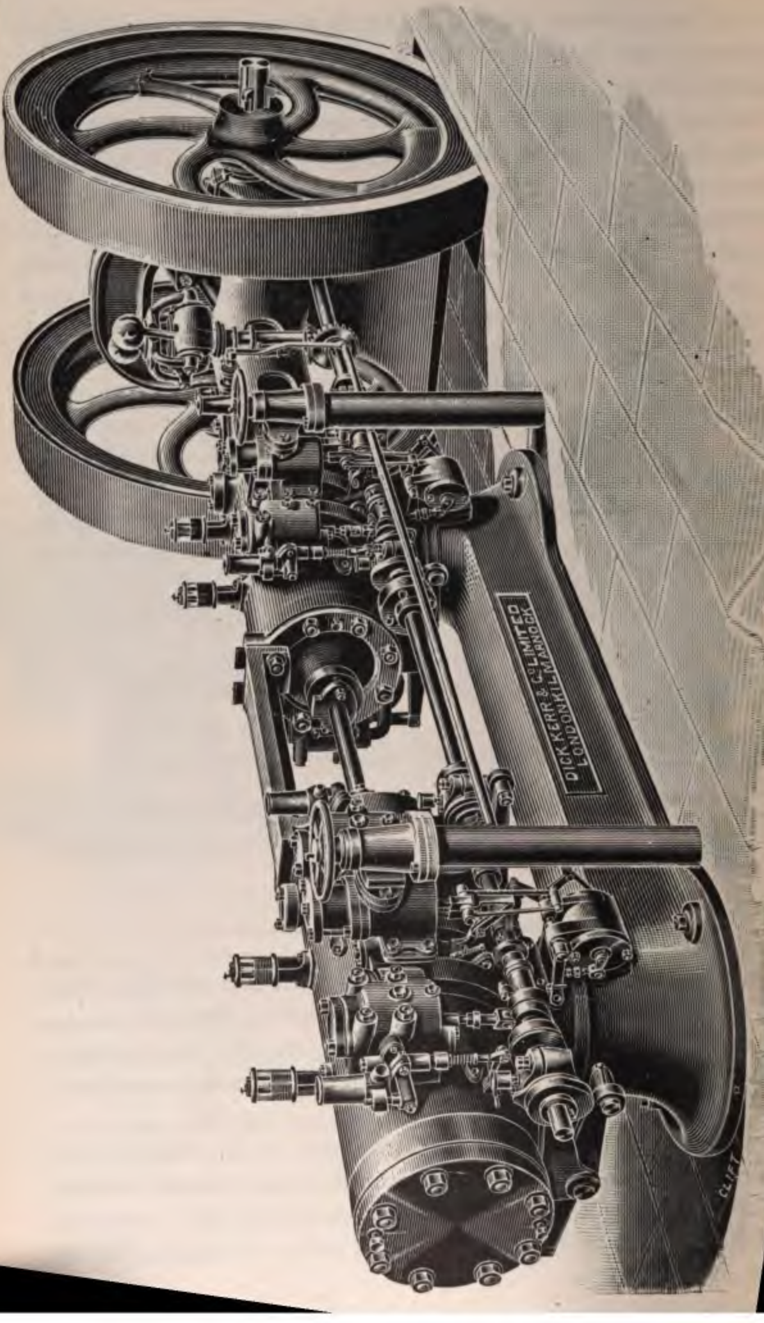


FIG. 94.—TANDEM DOUBLE ACTING GAS ENGINE.

operations in the two cylinders are as follows :—

Back Cylinder.		Front Cylinder, next crank.		
End of Piston.		End of Piston.		
back.	front.	back.	front.	
compression	*explosion*	exhaust	charging	1 rev.
explosion	exhaust	charging	compression	
exhaust	charging	compression	*explosion*	1 rev.
charging	compression	*explosion*	exhaust	

arrangement gives two explosions every revolution, or sion giving an impulse to a piston every stroke. The ders together give a complete Otto cycle every stroke, explosions take place in the front and back end of linder in regular order, so that the work is equally between the two. Very steady running can thus be l.

riking example of this type was found in the double-as engines used to drive the dynamos in the Central Light Station * in the city of Belfast. Many diffi-ere met and overcome in attaining sufficient steadiness ng, and reducing the cyclical variation in the speed of engines to enable the separately driven dynamos to tisfactorily in parallel upon a common bus bar sup-lectric current to the lamps. In the larger horizontal ines the two double-acting cylinders work tandem as in Fig. 94, on the above cycle. The end view, Fig. transverse section of this engine, Fig. 96, taken from r by Mr. McCowen, with the old longitudinal section 8), give a good idea of the design.

iron slide valves worked with a rocking shaft are gas admission, all the others are vertical lift valves of hroom type. The air and gas admission ports are on of each cylinder, and the exhaust valves on the side. Ignition is by hot tubes of ordinary wrought

"Electric Lighting in Belfast," by Victor A. H. McCowen, Proc. Eng., July 1896.

iron, nickel, steel, and porcelain, and controlled by timing valves which always open at the same point of the stroke.

The **Speed Regulation** was by a Buss governor, reducing the admission of gas, and only missing an explosion when running at less than one-third of full load. Compensating springs attached to the sleeve of the governor can be adjusted by hand for different loads whilst the engine is running.

The indicator diagrams, Fig. 97, show that the charges poor in gas ignited slowly and gave high pressure towards the point of release, causing back-firing in the exhaust occasionally. When the gas was completely cut out, the drive was not steady enough for good parallel working of the dynamos.

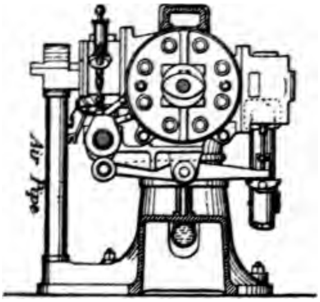


FIG. 95.—END VIEW.

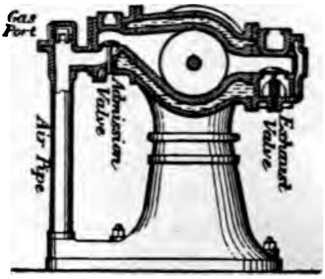


FIG. 96.—TRANSVERSE SECTION.

DOUBLE-ACTING CYLINDER.

These troubles were removed by Mr. Hartley's expanding cam. The cam working the gas valve is made up of three leaves, in planes at right angles to the axis of the cam shaft, and these are spread out or closed up by a sliding key which moves in a keyway cut in the cam shaft, and is controlled by the governor. The key and expansion cam are held in position by a detent when the cam engages the roller on the lifting lever during the opening of the gas valve, but as soon as this valve is fully opened the detent is released, leaving the cam again under the control of the governor. The disengaging lever is held by springs. The air admission is constant, only the gas is varied. At full load some of the air is drawn into the cylinder before the gas, and the cam is spread out and keeps the gas valve open during a greater part of the charging stroke. If the engine is running on light loads, and the speed rises slightly, the expanding cam is drawn up by the governor, and opens the gas inlet gradually less and less towards the end of the charging stroke, so that the cylinder is almost full of air with a small portion of explosive mixture near the ignition port. With mixtures poor in gas, prompt ignition is obtained by admitting the gas late in the charging stroke. The diagrams, Fig. 98, were taken with the engine running light, without cutting off gas supply completely. The initial pressure is 60 lb. per square inch, at mid-stroke 20 lb., and at release 3 lb. above atmospheric pressure. The graduation of the strength of the explosive charge in the gas engine for varying loads on the dynamo is shown in Fig. 99. Pre-ignition is seen at full load. This is practically Otto's plan of diluting the charge. The steadiness in speed attained at

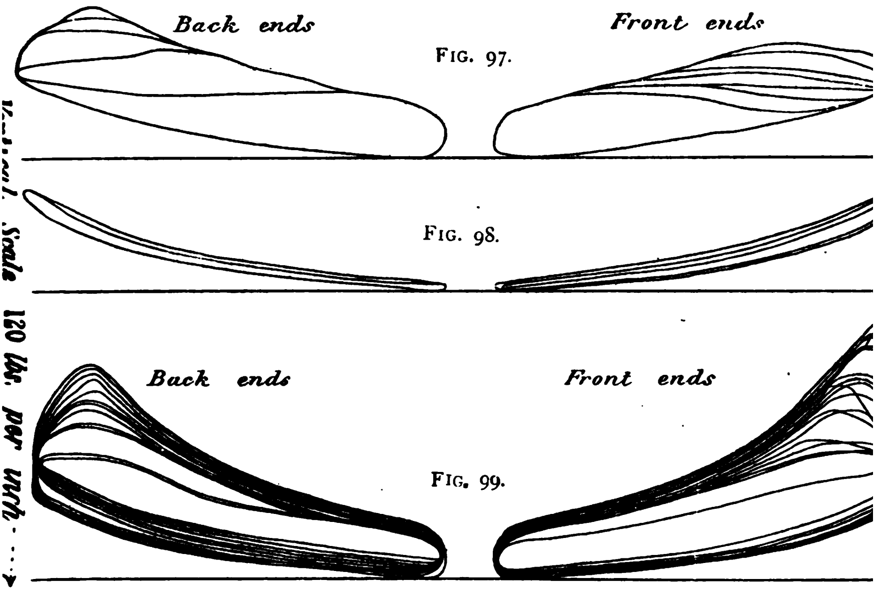


FIG. 97.

FIG. 98.

FIG. 99.

INDICATOR DIAGRAMS SHOWING GRADUATED EXPLOSIONS IN A DOUBLE-ACTING GAS ENGINE.

full load is such that the dynamos can be worked in parallel, but the consumption of gas is far too high for large engines.

The engine is **started by compressed air** admitted during the working stroke to the back end of the back cylinder by a special valve worked by a cam. The gas is cut off the back cylinder until an explosion occurs in the front cylinder, then the compressed air is shut off, the starting cam put out of action, and the gas turned on. A 6 horse-power electro-motor, taking its current from the mains, drives an air compressor which has two water-jacketed single-acting cylinders of 4·5 inches diameter and 8 inches stroke, with pistons on opposite cranks. The air receiver is 12 feet long by 4 feet diameter, and the working pressure 100 lb. per square inch.

There is a *water-jacket* around the engine cylinder, the end covers and piston-rod stuffing boxes. The latter have separate connections, fitted with regulating cocks, from the water-inlet pipe; the cooling water circulation passing upwards on each side cools the packing glands and piston rods, and discharges into the cylinder jacket. The water from an open cooling tank on the flat roof is circulated through the jackets by a small centrifugal pump driven by belt from the crank-shaft of the engine. The discharge to the cooling tank is into a long timber shoot with holes, so that the hot water is broken up into a shower, to hasten the cooling.

The diameter of the back cylinder is 13·75 inches, and of the front 13·5 inches, with 20 inches stroke. The tandem engine, running at 167 revolutions per minute, gives 120·5 indicated horse-power, with 334 explosions per minute, or two explosions per revolution. The mechanical efficiency of the engine at full load is 84·4 per cent. Each dynamo, driven through eight $\frac{7}{8}$-inch diameter cotton ropes, gives an output up to 286 amperes at 241 volts, or 92·3 electrical horse-power. The lowest consumption of gas was 20·9 cubic feet per indicated horse-power hour, and 27·4 cubic feet per electrical horse-power hour. For the sake of efficiency the engines are always worked as near to full load as possible; and yet the *average* consumption during the first year, 1895, was 34·8 cubic feet of gas per electrical horse-power hour, and 46·7 cubic feet per Board of Trade electrical unit of 1 kilowatt-hour generated. The average cost of gas, 53·7 cubic feet, per electrical unit sold came to 1·45*d.*

Comparing the light obtained with gas engine and dynamo to that by burning the same quantity of gas directly, we find that one unit, or 1000 watts for one hour, would supply 33⅓ lamps of 30 watts and of 8 candle-power each for one hour, and would give 266 candle-power for one hour. The gas used is 53·7 cubic feet. Therefore the light produced is 266/53·7 = 4·95 candle-power per cubic foot of gas per hour. The same gas used in ordinary burners gave 2·75 to 3 candle-power per cubic foot of gas per hour.

The calorific value of Belfast gas, as determined by a Junkers calorimeter, was 570 British thermal units per cubic foot at 14·7 lb. per square inch and 60° F.

Professor Kennedy tested the tandem double-acting engine, driving dynamo in the works at Kilmarnock, on the 14th September, 1894. In the six hours' full power trial the engine ran at 161 revolutions per minute, gave 111 indicated horse-power, and the output at the dynamo terminals was 84·3 electrical horse-power. The electrical was 75·9 per cent. of the indicated power, and the consumption of rich Kilmarnock gas was 23·9 cubic feet per electrical horse-power hour, and 18·2 cubic feet per indicated horse-power hour.

The high consumption of gas is due to several causes: (*a*) low compression of the charge before ignition only to 50 lb. per square inch above atmospheric pressure, gives a corresponding low mean effective pressure, 40 to 50 lb., during the working stroke. This defect may also be owing to the tendency, inherent in the cycle and design, to overheating of the cylinder, which causes premature ignitions and other like troubles when higher compression is used. (*b*) The method of governing by varying the ratio of gas to air in the charge cannot but result in a largely increased rate of consumption of gas at light loads. The curves, Fig. 99, show pre-ignition, and combustion gradually retarded by the dilution of the charge. (*c*) The cooling action of the cylinder walls and covers, and piston rods, necessary for good lubrication for continuous running, must also reduce the thermal efficiency. (*d*) Low piston speed, and too early ignition.

The following are the principal **results of tests** made on one of the four large tandem double-cylinder double-acting horizontal engines and dynamo, by Mr. V. A. H. McCowen at Belfast, in April 1896. Each trial lasted half an hour, and the load was kept constant for that time. The engine was run at 20 per cent. overload down to quarter-load. When running light the indicated horse-power was 18·8. The rate of gas consumption is seen to increase rapidly at light loads and to be excessive with less than three-quarters of full load. The speed is fairly uniform.

TRIALS OF TANDEM DOUBLE-ACTING GAS ENGINE AND DYNAMO (Belfast).

Load factor . per cent.	120	100·8	74·8	52·3	25·2
Revolutions per minute .	166·5	167·5	168	166	168
Amperes	285·7	241·5	179·4	125·2	60·2
Volts	240·9	240·2	240	240·1	240
Kilowatts	68·8	58·1	43·1	30·1	14·5
Indicated horse-power, I.H.P.	120·5	101·4	80·2	64·4	45
Electrical H.P. ÷ I.H.P. per cent	76·6	76·8	71·8	62·7	43·2
Total gas used, cubic feet per hour	2494	2230	2020	1906	1748
Gas used per I.H.P.-hour cubic feet	20·9	22·3	25·6	30·1	39·2
Gas used per electrical H.P.-hour . . cubic feet	27·4	29·0	35·5	48·0	91·7
Total water used per hour, lb.	21,830	13,100	22,560	12,720	12,750
Temperature of water in the cooling tank in degrees F.	85·5	84·5	84·0	86	83·5
Temperature of water leaving jackets in degrees Fahr. .	119·0	108·4	131·7	106	112

The gas includes that used to heat the ignition tubes.

In the single-cylinder double-acting engine, at 160 revolutions per minute and 57·6 indicated horse-power, the gas used was 21·2 cubic feet per indicated horse-power hour, and 29·4 cubic feet per electrical horse-power hour.

he year 1897 the average cost of gas was 1·3*d.* per electrical unit sold. Steam engines were reverted to for driving dynamos at Belfast Electric Light Station in July 1898.

Steam Starter.—When these large gas engines made by Messrs. Dick, Kerr and Co. are worked with producer gas, one method of starting is to use the steam from the gas plant boiler to work the piston in the back end of the cylinder, until the charge is fired in the front end. The starter is fixed on the back cover of the cylinder, Fig. 100, and consists of a stop valve S closed by the steam pressure, and having a spindle with screw and lock nut. Steam is stored in a reservoir R. To start the engine, the back admission valve is put out of action by moving the admission lever roller clear of the cam lift. This movement also pulls back the firing valve out of action, and the back exhaust valve is arranged to open every revolution instead of every two revolutions. The steam-valve lever L is worked by hand to allow steam to push the piston to the end of its stroke. Then the steam valve is closed and exhaust opened during the return stroke of the piston, until the charge is fired at the front end of the cylinder and the engine starts. The steam is shut off, and the rollers for the admission and ignition timing valves are put back to their normal position.

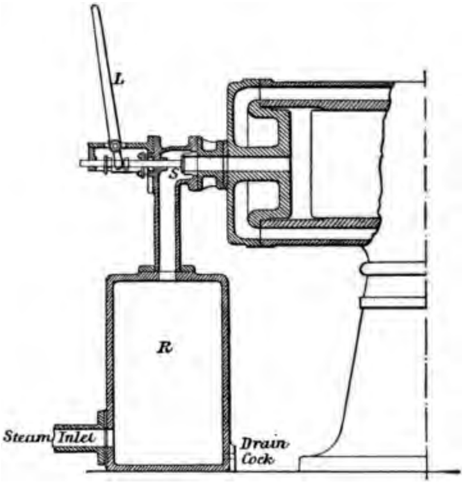


FIG. 100.—STEAM STARTER.

Griffin Duplex Gas Engine.—A vertical gas engine Fig. 101, is made by the GRIFFIN ENGINEERING COMPANY, Bath. Supported on four massive steel columns are two vertical cylinders side by side in a single water-jacket, and fitted with two long trunk pistons coupled together at their lower ends by a steel cross-head to which is attached the one connecting rod driving the crank. The top cover is water-jacketed and has the inlet and exhaust valves opening direct into each cylinder, and worked by rocking levers from a cam on a vertical shaft driven by 2 to 1 bevel gearing on the crank-shaft. Ignition is by hot tubes, arranged side by side in the chimney and heated by one Bunsen flame.

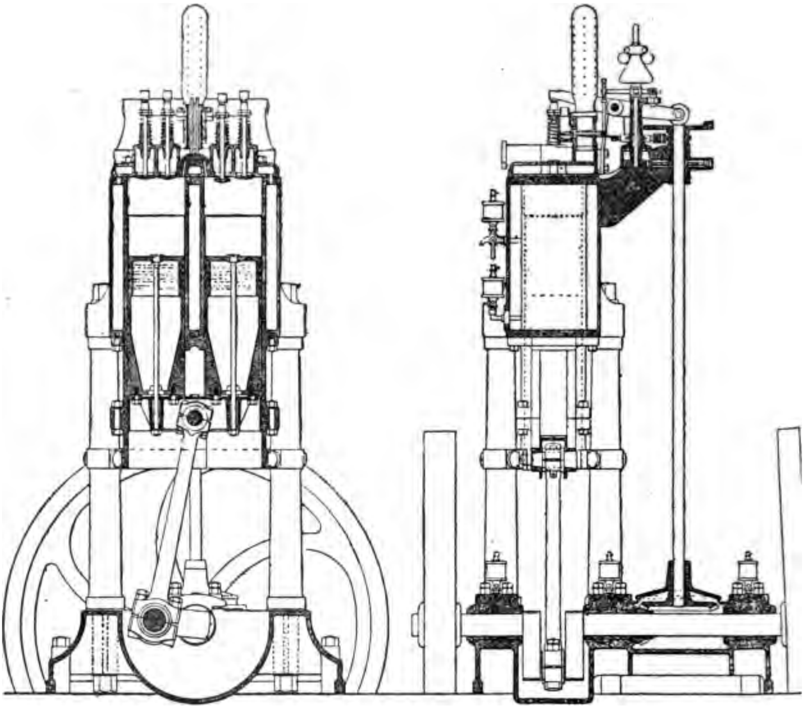


FIG. 101.—GRIFFIN DUPLEX GAS ENGINE.

One inlet valve supplies both cylinders, controlled by a centrifugal governor, on the hit-and-miss, all or none plan, without graduation of the charge, thus securing best economy. The crank and tail pins of the connecting rod are thoroughly lubricated from oil wells on the cross-head, which are fed by sight-feed lubricators fixed to the water-jacket. The engine works on the four-stroke Otto cycle, and there is an impulse every revolution. The charge is compressed to 50 lb. per square inch before ignition, giving with Bath lighting gas a mean working pressure of 82 to 85 lb. per square inch.

Two pairs of these engines drive dynamos to supply 800 incandescent lamps in a London warehouse. The cylinders are 10·25 inches diameter with 15 inches stroke, and at 180 revolutions per minute give 46 indicated horse-power and 40 brake horse-power. It is stated that the cost of gas and lubrication is about 1½*d.* per B.T.U.

Burt's Acme Gas Engine.—In the *Acme* twin-cylinder horizontal gas engine, made by Messrs. BURT & CO., Glasgow, we find a novel device to increase the range of expansion of the products of combustion beyond the original volume occupied by the charge before compression. There are two horizontal cylinders with two pistons, the two crank-shafts being connected by spur wheels, geared in the ratio of 2 to 1. The cylinders are side by side, one being shorter and smaller than the other. The piston in the smaller cylinder sweeps a less volume than the larger one, and makes half the number of strokes. Any desired expansion of the charge may be obtained by proportioning the stroke and diameter of the pistons. The two spur wheels are geared so that when the larger and faster moving piston is at the end of its in or out stroke, the smaller piston is about 45° of its crank from the dead points. The two cylinders are joined by a wide port, and there is only one automatic lift valve or feed valve to admit the charge of gas and air. Ignition is by hot tube opening into the cylinder. The firing and exhaust take place when the smaller piston uncovers ports opening from the cylinder at about one-seventh from the beginning and end of its stroke, that is, when the larger piston is at its dead points.

The difficulty with this engine was to get the smaller piston to work well. The wheel gearing was also objectionable after it became worn, because the teeth necessarily wore unevenly. About 200 engines were made altogether. The main reason for giving up this engine was the great expense of manufacture. When prices fell, on the lapse of the Otto master-patent, the manufacture of the Acme had to be abandoned as it did not pay.

Trials.—The Acme horizontal engine was carefully tested by Professor W. T. Rowden, of Glasgow, in November 1889. A two horse-power nominal engine had the two cylinders and their strokes of such dimensions as to give the volume

After charging	100	After expansion	125 (about)
„ compression	33 (about)	„ exhaust	50 „

Thus a large amount of spent gases is left in the cylinder after exhaust to mix with the incoming gas and air, and the limit of expansion is necessarily very much restricted by this dilution of the charge.

With full load, at 172 revolutions per minute, this engine gave 3·24 brake horse-power on a consumption of 17·6 cubic feet of Glasgow gas per brake horse-power hour, not including the ignition-tube gas, an excellent result. At 1·3 brake horse-power the gas used was 25 cubic feet per brake horse-power hour.

An engine of 6 horse-power nominal, tested by Professor Rowden, gave 8·28 brake horse-power at 170 revolutions per minute, on a gas consumption of 17·3 cubic feet per brake horse-power per hour; and in another trial 7·8 brake horse-power on 16·83 cubic feet per brake horse-power hour, that is an average of 17·5 cubic feet per brake horse-power hour.

In April 1892 a trial by Professor Jamieson of a 12 horse-power nominal Acme engine gave 13 brake horse-power at 19·3 cubic feet per brake horse-power hour. The heating value of this rich Glasgow gas is 810 B.Th.U. per cubic foot, and that of London gas 630 B.Th.U. per cubic foot at 32° F., and 14·7 lb. per square inch, or in the ratio of 9 to 7; so that 17·5 cubic feet of Glasgow gas would give the same heat as 22·5 cubic feet of London gas.

Acme high-speed engine.—The Acme Gas Engine Company brought out an Otto cycle high-speed vertical engine (Burt and McGhie patents), with two single-acting cylinders arranged in tandem, Fig. 102. The top and bottom pistons are fixed on the same rod R, which passes through a large water-jacket W, the packing being ordinary Ramsbottom rings. The upper sides of the pistons are acted on by the gases and the r part of the bottom piston forms a guide. The pair of ns drives the crank by one piston rod of five cranks in h. The gas and air are admitted by valves A of the room type, actuated by cams on a horizontal shaft S at angles to the cylinders, and worked by an upright from a

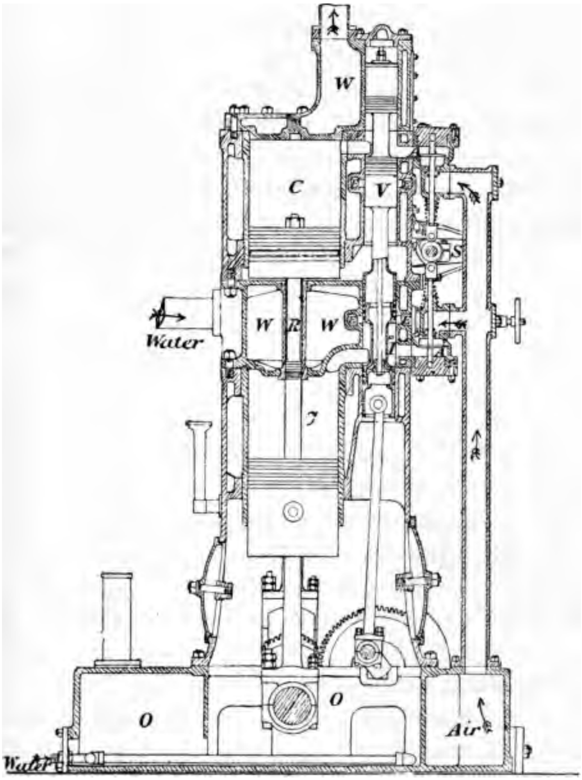


FIG. 102.—ACME TANDEM VERTICAL GAS ENGINE (VERTICAL SECTION).

l crank-shaft. The design, Fig. 102, is somewhat on steam le lines. One novel feature is the piston valve V, driven the small crank-shaft geared to the main shaft in the ratio 2 through spur wheel and pinion. The double piston V makes half the number of strokes of the main pistons, controls the exhaust, time of ignition and admission of the charge into the combustion chambers C above the pistons. At the end of their up strokes the pistons are near the cylinder covers, and the compression or combustion chamber consists partly of the ports and annular space around the piston-valve stem to the admission valve A. In Fig. 102 the pistons are at the end of their down stroke, which was charging or admission in the top cylinder and explosion in the bottom one. The pistons are on the point of commencing their up stroke, which is compression in the top cylinder and exhaust in the lower one through port E to the atmosphere. Ignition is by hot tube through ports I uncovered by the piston valve V.

The piston valve, exposed to the burning gases and next to the incoming charge, appears to be a weak point in a gas engine, and likely to give trouble in various ways in continuous working.

Each cylinder is fitted with a governor which stops gas admission, and so misses an explosion when the speed is too high. A stop valve is also fitted on each cylinder, so that the engine can be run with one or more cylinders as desired. The lower part of the engine being closed in the base, forms an oil chamber in which the crank works. The lower ends of the piston and piston valve are lubricated by the splash of the cranks and connecting rod dipping in the oil bath. The top cylinders only have lubricators. The engine is specially designed for steady driving at a high speed for electric lighting. The connecting-rod joints are kept constantly in thrust or compression, and so knocking is avoided. During the down stroke the top brasses on the crank pin are kept constantly against the pin by the explosion in the lower cylinder, while the upper piston is going down drawing in a charge of gas and air. Again, during the next up stroke the lower piston is exhausting, while the upper one is compressing the charge to a pressure of over 100 lb. per square inch, which is sufficient to keep a thrust on the connecting-rod pin at a speed of 400 revolutions per minute without knocking. When the lower piston is exhausting the upper one is compressing, and *vice versâ*, each working on the four-stroke cycle. The piston valves are also kept constantly in thrust by cushioning at the top end of cylinder.

In the 150 horse-power electric light Acme engines at

Belfast, two lines or pairs of these tandem cylinders work with pistons on opposite cranks, and coupled direct to the dynamo shaft give two impulses per revolution. When the engine runs at 380 revolutions per minute, and at full load, no explosions being missed, 190 impulses per minute are obtained in each cylinder, or a total of 760 explosions per minute in the engine. A fly-wheel, 3 feet in diameter, is fixed on each end of the crank-shaft, the one at the dynamo end weighing 28½ cwt., and the other 24½ cwt., so that very steady running is obtained. The piston speed is 630 feet per minute, not greater than in the usual type of slow-speed gas engines.

Three lines of tandem cylinders give, at full load, three explosions per revolution, that is, from six single-acting cylinders and at 400 revolutions per minute there are 1200 impulses per minute or 20 per second, which should give a small cyclical velocity variation and uniform drive.

Only a few of these large vertical tandem engines were built, and the design has recently been modified, doing without the piston valve.

Trials.—A 14 nominal horse-power Acme gas engine which had been running for some months, driving a dynamo in the Belfast Exhibition of 1895, tested by Mr. McCowen, gave, Fig. 103, when running at 192 revolutions per minute, 28·86 indicated horse-power, and 19·23 electrical horse-power at dynamo terminals, on a gas consumption of 18·02 cubic feet per indicated horse-power hour, or 27·04 cubic feet per electrical horse-power hour. The heating value of the Belfast gas, at 60° F. and 14·7 lb. per square inch, was 570 B.Th.U. per cubic foot. The Acme engine required in 1 hour 18·02 × 570 or 10,271 B.Th.U. to give 1 horse-power. Now the thermal equivalent of 1 horse-power for 1 minute is $\frac{33{,}000}{778} = 42{\cdot}42$ B.Th.U., and for 1 hour is 2545 B.Th.U.; so that of all the heat supplied to the Acme engine it turned into work on the pistons 2545/10271 = 24·8 per cent., a fairly good thermal efficiency for the engine.

In November 1896, Professor W. T. Rowden tested a 14 nominal horse-power Acme engine, using **blast furnace gas** for electric lighting at the Glasgow Ironworks, Wishaw. The engine cylinder was 12 inches diameter, and stroke 20 inches, and gave 28 brake horse-power easily with ordinary town gas. Professor Rowden found that the failure of the engine to give sufficient power with blast furnace gas was due to a serious delay in the ignition of the compressed charges. The engine gave only 14·4 brake horse-power. He was, therefore, led to design an ignition valve having very rapid motion, and succeeded in firing the mixture of blast furnace gas and air promptly with the ordinary ignition tube. During a trial with blast furnace gas the engine was driving a dynamo, and had a brake load on one of the fly-wheels. At 197 revolutions per minute the total power was 20 brake horse-power, and the gas used, as measured by the fall of the gasholder, 1885 cubic feet per hour, that is, 94·2 cubic feet per brake horse-power hour. Adding about ½ horse-power spent in driving the fan, the consumption would be reduced to 91·9 cubic feet per brake horse-power hour. Professor Rowden is of opinion that the gas from the Wishaw blast furnaces is superior in quality and more uniform in composition than average gas from a Dowson producer (see analysis, page 606).

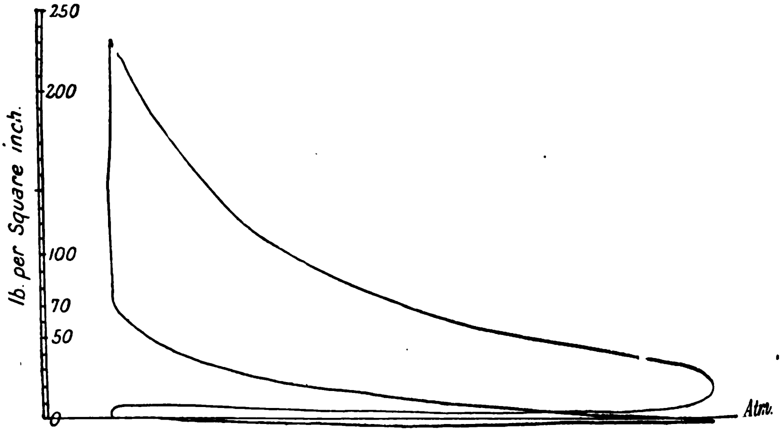


FIG. 103.—INDICATOR DIAGRAM. 14-H.P. ACME GAS ENGINE.

Revolutions per minute 192 ; explosions per minute 77 ; mean effective pressure 66·3 lb. per square inch.

The following table gives the results of various trials of the cme high-speed engine, and Fig. 104 is an average indicator iagram.

TESTS OF 150 I.H.P. ACME VERTICAL TANDEM ENGINE COUPLED TO DYNAMO. By Mr. Victor A. H. McCowen.

ace . . .	Glasgow.							Belfast	
te . . .	Oct. 1895	Mar. 1896	May 29 and 30, 1896					Nov. 1896	
ration of test .	..	6 hours	5 hours	½ hour	½ hour	½ hour	½ hour	½ hour	½ hour
an speed, revs. per min. . .	350	395	373·2	370	384·5	390	395	410	410
an indicated H.P. . .	127·2	..	..	140	101·3	80·7	59·8	..	..
an electrical H.P. .	79·5	96·8	97·4	109	72·7	48·8	24	88·9	52·1
used, cubic ft.—									
Per indicated H.P. hour .	15·9	..	..	18·95	20·8	21·2	21·9	..	..
Per electrical H.P. hour .	25·4	24·9	27·6	24·4	29	35·1	54·5	30·7	36
Th.U. per cubic ft. of gas . .	750	..	..	..	..	..	..	570	..

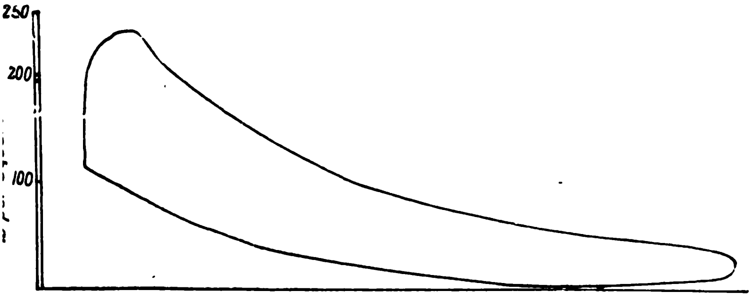


FIG. 104.—INDICATOR DIAGRAM. ACME VERTICAL TANDEM ENGINE.

350 revolutions per minute; 147 explosions per minute; mean pressure 73 lbs. per square inch; 29·6 Indicated H.P.

The heating value of Glasgow gas, as determined by Junkers calorimeter on 30th October, 1896, was 750 B.Th.U. per cubic foot at 60° F., and 14·7 lb. per square inch.

CHAPTER VIII.

ENGINES WITH SEPARATE PUMP, AND IMPULSE EVERY REVOLUTION.

THE Barnett type of compression gas engine has, besides the motor cylinder, an auxiliary cylinder, with pumping piston or displacer for drawing in, mixing and sending the charge, either into a compression reservoir, or else supplying the motor cylinder direct. The pumping strokes are thus carried out in the separate cylinder, and there is an impulse for every revolution of the crank-shaft. The extra first cost and additional friction of mechanism, with two cylinders instead of one, render this engine expensive.

Clerk.—One of the early engines of this type was the first engine exhibited by Mr. Dugald Clerk, at Kilburn, in 1879. The pump and motor cylinders were each 6 inches in diameter by 8 inches stroke, and the maximum power developed was 5 horse-power, the speed running up to 300 revolutions per minute. The mixture of gas and air was pumped into a reservoir at 70 lb. per square inch above atmospheric pressure. The compression reservoir contained about twelve charges from the pump, and one serious trouble was back ignition into this reservoir, because it was found that the explosion of the compressed gases therein stopped the engine. Another difficulty was shock due to the too rapid ignition of the charge in the motor cylinder. This was overcome by changing the shape of the compression space.

Figs. 105 and 106 show the sectional elevation and plan of the next Clerk gas engine, built by Messrs. L. Sterne and Co., of Glasgow. The Clerk engine, which reached this stage of its development in 1881 (drawings from Patent

No. 1089 of 1881), was designed to give an impulse or explosion every revolution, performing in the same time a complete cycle of operations. To do so, Clerk used an auxiliary cylinder, with pump piston for drawing in the measured charge of air and gas and delivering it into the motor cylinder, where it was compressed by the motor piston before combustion.

C represents the working cylinder, open at one end, and having a long piston P joined to the crank (not shown) by a connecting rod as in ordinary engines. This cylinder, surrounded by water-jacket W, has a conical compression space A into which the charge of gas and air is compressed before being fired. The compression space is one-half of the volume swept by the piston from the exhaust port to the end of stroke. The exhaust ports E, E open into an annular space

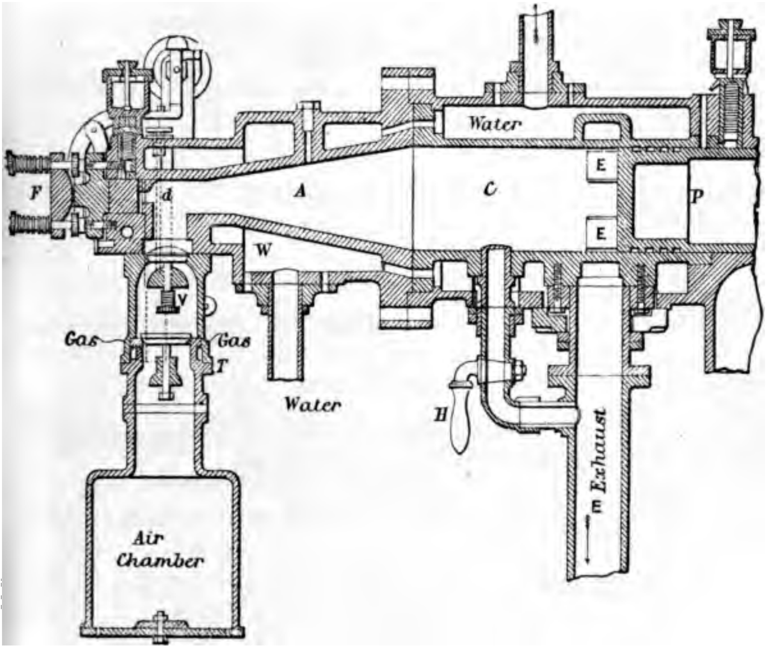


FIG. 105.—CLERK GAS ENGINE, 1881 (LONGITUDINAL SECTION).

around the cylinder, leading to the exhaust pipe E, by which the burnt gases escape when the piston uncovers these ports.

It was difficult to proportion the pump B and motor cylinder, and the shape of the passages. Any error in these caused discharge of unburned gas at the exhaust ports. The pump or displacer piston D is worked from a crank pin in an arm of the fly-wheel, and its crank is set a little over 90° in advance as the motor crank on the main shaft. During its forward stroke D draws the explosive mixture, 1 volume of coal gas to 8 of air, into the cylinder B. First, gas is drawn by the pipe S, Fig. 106, the slide port *b*, the conduit *g*, the valve T, and the pipe L into B, through an annular orifice round the baffle-plate made to check the eddies or inrush of the gas and "to diminish the chances of back ignition." The conical-seated valve T has holes round it to admit a proper mixture of gas and air—the latter being drawn through the india-rubber flap valve at the bottom of air chamber.

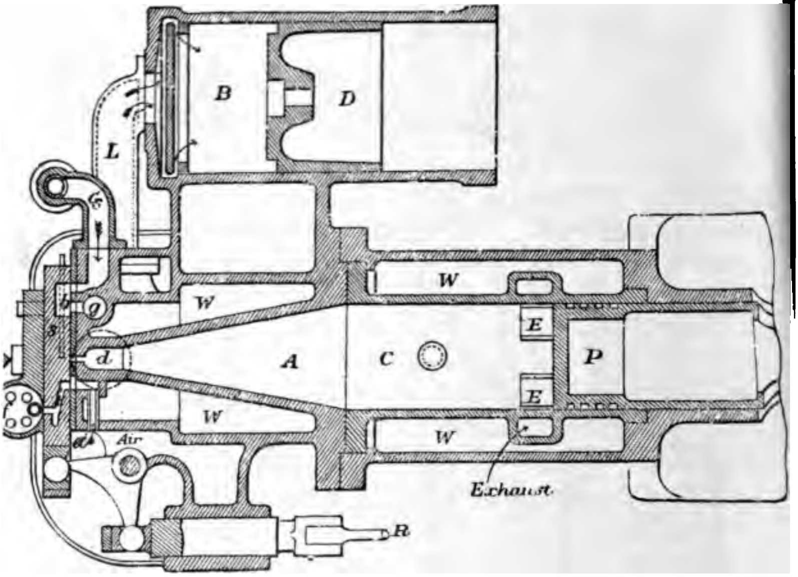


FIG. 106.—CLERK GAS ENGINE, 1881 (SECTIONAL PLAN).

About the middle of the forward stroke of the pump piston D the slide valve *s* closes the orifice *g*, and thus cuts off the supply of gas by the slide port *b*, so that pure air alone is admitted into the passages by the valve T during the second half of the stroke. The forward stroke of D is completed while the working piston P is moving forward rapidly near the middle of its working stroke. In the return stroke, D now begins to compress the charge a little, but this does not open the valve V, as the pressure on the other side is much greater.

Near the end of the forward stroke of P the exhaust ports E are uncovered, the burnt products begin to flow out from the periphery of the cylinder through E, whilst the pump piston D discharges the air out of B back through the pipe L, the valve V lifted by the suction of the exhaust, and the passage *d*, into the compression chamber A of the working cylinder. The air displaces or sweeps before it the products of combustion out into the exhaust E. During the second part of its return stroke the pump piston D also forces the explosive mixture out of B after the air into A, when the motor piston P is at the first part of its return stroke. This action continues until just before P covers the exhaust ports. Almost the whole of the burnt gases have been expelled, and a portion of the newly introduced charge is also following; but since this first portion is nearly pure air, it may be allowed to pass out after the products of combustion by the exhaust, without losing any appreciable quantity of the mixture rich in gas behind it.

However, owing to the difficulty of exactly proportioning the volumes of the displacer and motor cylinders, as well as to the tendency of gases to mix and not remain in stratified layers, some of the unburned gas usually does escape with air into the exhaust. At the same time some of the residual products may be retained to prevent loss of the unburned gas mixed with it. Mr. Clerk says, " in the smaller engines it was hardly possible to avoid the discharge of some unburned gas at the exhaust ports during the operation of charging."

The exhaust is now closed by piston P in its return stroke; the piston D begins its next forward stroke, and the valve V is closed by its spring. Both of these automatic lift valves are provided with quieting pistons, which compress air and act as guides and dashpots to check the sudden fall of the valves on their seats.

The explosive mixture in C and A is compressed by P until it occupies only the conical clearance space A of the cylinder, then the charge is fired. This is done by a flame carried under pressure in the slide *s*, moved to and fro by the bell-crank lever acted on by connecting rod R joined to an eccentric on the crank-shaft. A chamber *b′* in the slide valve S communicates with the bottom of the combustion chamber A, and receives a regulated quantity of the explosive mixture through a grating or " diffuser " when in the position Fig. 105. This mixture in *b′* is lighted at the constant burner *f*, getting air from atmosphere through the little passage *a*, Fig. 106. After the chamber *b′*, carrying the flame, is isolated by the movement of the slide, it receives more of the compressed mixture through the "grating"; this augments the burning and pressure until *b′* is brought opposite *d* and shoots a tongue of flame into the compressed charge. Compare the Otto slide-valve ignition (page 106).

The slide cover is pressed against the slide valve by the spiral springs F. In starting the engine, turn the cock H, Fig. 105, which opens the back of the motor cylinder to the exhaust, so as to diminish the compression. There is an explosion every revolution *at full load*, and the operations in this engine are as follows:—

For the *displacer cylinder;* during the forward stroke of piston it sucks in—

1. An explosive mixture of gas and air necessary for the next charge in the working cylinder:

2. Towards end of stroke only air, which is supposed not to mix or diffuse into the explosive mixture.

During the return stroke the displacer piston drives into the motor cylinder, aided by the suction of the exhaust—

1. The scavenger charge of air ;

2. The explosive mixture.

By the indicator diagram, Fig. 107, from the *motor cylinder* it is easy to follow the cycle. The full lines give the mean diagram without the first part of the explosion line, which is supposed to be vertical. The dotted lines show the compression and expansion curves calculated for air without loss or gain of heat under similar conditions of temperature and pressure.

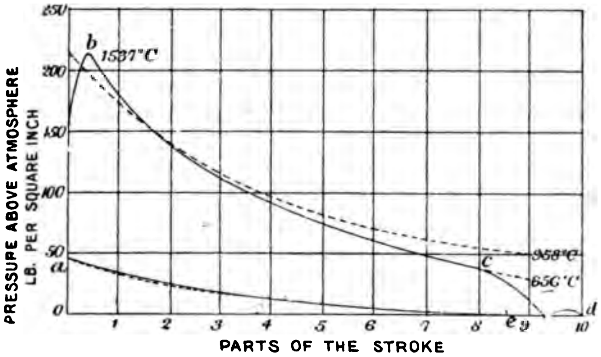


FIG. 107.—DIAGRAM FROM CLERK GAS ENGINE.

From *a* to *b*, explosion of the mixture at nearly constant volume.

b to *c*, expansion of the burning gases, first above and then below the adiabatic curve.

c to *d*, exhaust begins, and the products of combustion are driven out before the air and incoming charge from the displacer cylinder.

d to *e*, end of exhaust and charging.

e to *a*, compression of the mixture to one-third its original volume, nearly along the adiabatic.

Trials.—At the Crystal Palace Electrical Exhibition in 1882, a Clerk gas engine, made by L. Sterne of Glasgow, was tested by Professor W. G. Adams, F. J. Sprague, and others.* The indicator diagrams, Figs. 108 and 109, were taken from the motor and pump cylinders, at full load. The gas was measured by a meter furnished by the Standards Department of the Board of Trade. The brake power was absorbed by Froude's water dynamometer. The engine was 6 horse-power nominal, with pump and motor cylinders 6 inches in diameter, the stroke of the displacer or pump being 18 inches, and that of the motor piston 12 inches. Of the gross indicated power, 0·71 horse-power spent in the pump was deducted to give the available indicated power. The chief results are:—

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* Compare results of tests, page 112.

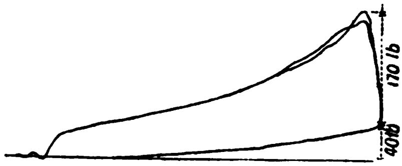

FIG. 108.—INDICATOR DIAGRAM. MOTOR CYLINDER.

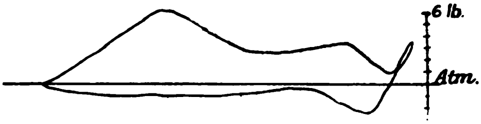

FIG. 109.—INDICATOR DIAGRAM. PUMP CYLINDER.
CLERK GAS ENGINE: 6 H.P. FULL LOAD.

TRIALS OF CLERK GAS ENGINE. Crystal Palace, 1882.

Load	full	medium	slight
Duration of trial, minutes	30	30	10
Revolutions per minute	144·7	140·3	145·5
Pressure before ignition (above atmospheric), lb. per square inch	41	41	40
Explosion pressure, lb. per square inch	180	85	78
Mean effective pressure, lb. per square inch	60·72	44·75	37·56
Indicated H.P., nett	6·82	4·67	3·96
Brake H.P., nett	3·77	2·12	1·31
Mechanical efficiency, per cent.	55·4	45·5	33·1
Power spent in pump and engine friction	3·04	2·54	2·65
Gas used per hour, cubic feet	244	192	180
Gas used per brake H.P. hour	64·8	90·6	137·4
Heating value of gas, B.Th.U. per cubic foot (calculated)	633	633	633
Heat turned into useful work, per cent.	6·2	4·5	2·9

During the full-load trial fourteen exhaust or back explosions were noted. Indicator diagrams were taken showing back ignition and premature explosions.

On reducing the load the gas was throttled down to give an explosion every revolution. This retarded the combustion. The exhaust port was too large, and "there was direct loss of explosive mixture through it before compression."

The result was excessive consumption of gas per brake horse-power hour, even at full load, and this was greatly increased as the load was reduced. Apparently the Clerk engine had given better economy when tested beforehand in Glasgow, using richer coal gas.

Mr. Clerk gives the following particulars of test made by Mr. G. H. Garrett, of the firm of Messrs. L. Sterne and Company, on a 6 horse-power nominal, at the works in 1885.

Diameter of cylinder, 7 inches; length of stroke, 12 inches; speed of engine, 146 revolutions per minute; mean pressure, 53·2 lb. per square inch; giving in motor cylinder, 9 indicated horse-power, and 7·23 brake horse-power. Consumption of rich Glasgow gas, 30·42 cubic feet per brake horse-power per hour. The maximum pressure is 195 lb. per square inch above atmosphere. The pressure before ignition is 48 lb. per square inch above atmosphere. Power spent in pump 0·86 horse-power. The lower dotted line, Fig. 107, shows compression without loss of heat to the same volume as exists in clearance space. Temperature before compression, 17·3° C. (63° F.). Temperature after compression, 150·5° C. The upper dotted line shows the work done by air heated to 1537° C., supposing it to lose no heat during expansion, except by doing work.

It will be observed that here the expansion is only continued until the volume of the burning gases becomes equal to the volume occupied by the charge before compression. Moreover, compression takes place in the motor cylinder. In ordinary working, the gas consumption was usually found to be much greater than these figures indicate, at less than full load, and especially with the smaller engines. The greatest difficulty was found to be in governing *economically.* A gridiron slide valve, controlled by a centrifugal governor, was used to cut off the supply of gas and air when the speed became too inrushing current of air from the exhaust port B, and also avoids loss of the rich mixture along with the burnt gases, which was a defect in the Clerk engine. At a certain point in this return stroke the exhaust valve is closed, and the charge is compressed through valve O into the explosion chamber M and the clearance space A by both ends of the piston during the remainder of the stroke. When the piston commences its next out stroke the timing valve is opened and the compressed charge is fired by the heated tube, Figs. 111 and 112. The purest part of the charge is first ignited in the passage M, and the flame spreads round to the explosion chamber A in the motor cylinder. The same operations are repeated. By means of this device the one cylinder, with long differential trunk piston, does the work of separate pump and motor cylinder, giving an impulse to the crank-shaft at every revolution. The number of working parts are few and simple. The extra pump greatly reduces the mechanical efficiency. A centrifugal governor regulates the speed by completely cutting off the gas.

Trials.—In July 1895 the Author made a brake test of a Trent gas engine under ordinary working conditions, as it had been regularly running for three years. The engine was 4 horse-power nominal, to give 6·5 effective horse-power with ordinary coal gas, the diameter of motor end of piston 7·75 inches, and of pump end 10 inches, with stroke 12 inches. The effective area of the pump end is the difference between the areas of the two circles, that is, of the ring exposed to the pressure of the gases. During a run of two hours at 4·2 brake horse-power, the limits of speed were 200 and 204 revolutions per minute, and the average 202·3 revolutions.

Indicator diagrams were taken every 5 minutes, and occasionally half minute diagrams, all traced on the one card, to give the variations. Figs. 113 and 114 are fair samples of diagrams taken at the same time from the motor end and pump end of the cylinder. The pressure before ignition of charge was only 37 lb. per square inch above atmospheric giving an explosion pressure about 120 per square inch; an the mean pressure from all diagrams during the trial wa 30 lb. per square inch. The engine ran best with the ignitio through the inlet valve E to the pump, and the charging valve O, which admits the fresh mixture into the side passage M or combustion chamber. R is the exhaust valve. Fig. 111 also gives a horizontal section of cylinder A, combustion chamber M, and the charging or pump cylinder C.

The long trunk piston has two parts or heads of different diameter, the smaller head B working in the motor cylinder A, whilst the larger head D acts as pump in the charging end C. The pump and motor ends of the cylinder are connected by the side passage M, along which the flame is propagated rapidly from the ignition tube, and regulated by the timing valve V. The cylinder is water-jacketed at every available point, and exposes a very large cooling surface to the working fluid. The lift valves are held on their conical seat by spiral springs, and opened by levers on one common link which is worked by a cam on the crank-shaft.

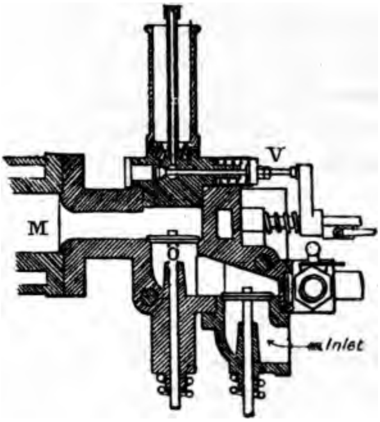

FIG. 112.—TRENT GAS ENGINE: CHARGING VALVES.

During the explosion or out stroke of the piston from the one end A of the cylinder, the motor piston head B is driven by the burning and expanding gases, whilst the fresh mixture of gas and air for the next charge is drawn through inlet valve E, Fig. 112, and port N, Fig. 111, into the annular space left by the large head D of the piston in the other end C of the cylinder. Sufficient energy is now stored up in the fly-wheel to carry the engine through the return stroke. During the first part of the return stroke the exhaust valve R is opened, and some of the burnt gases are driven out by the small motor end B of the piston before the incoming charge that is being forced from the annular space in cylinder C by the pump end D of the piston. The shelf or partition H (Fig. 111) is designed to divert the products that might remain. There is a large cooling surface of these walls exposed to the gases during explosion.

The result is a rather high rate of gas consumption as compared with that of engines working at double the compression.

The speed was regular, owing to the impulse every revolution; but, as in the small Clerk engine tested by Professor Adams and F. J. Sprague at the Crystal Palace, the economy was not satisfactory.

In November 1893 the Author, assisted by Professor Alfred Hay, D.Sc., made a trial of another Trent gas engine at Basford. The diameter of the piston was 12 inches at the motor end and 15 inches at the pump end, with stroke 20 inches. The engine ran very steadily under unfavourable conditions for efficiency and economy, at about two-thirds of full load. There was insufficient supply of cooling water for the cylinder jacket. The principal results are:—

TRIAL OF TRENT GAS ENGINE.

Duration of trial, 5 hours.
Revolutions, 170 per minute.
Explosions, 159·2 ,,
Pressure before ignition, 60 lb. per square inch (absolute).
Explosion pressure, 115 ,, ,, ,,
Mean effective pressure, motor cylinder, 25·6 lb. per square inch.
Mean pressure, pump cylinder, 5·4 ,, ,,
Indicated horse-power, motor, 23·3.
,, ,, pump, 2·8.
,, ,, nett, 20·5.
Brake horse-power, 14·3.
Mechanical efficiency, 70 per cent.
Gas used per hour (including ignition), 504 cubic feet at 60° F., and 14·7 lb. per square inch.
Gas used per indicated H.P. hour (gross) 21·6 cubic feet.
,, ,, ,, (nett) 24·5 ,,
,, brake H.P. hour 35·2 ,,
Heating value of town gas, 622 B.Th.U. per cubic foot.
Cooling water through jacket, 1155 lb. per hour.
Rise of temperature of water, 110·7° F.

Thermal efficiency:—

Heat converted into indicated work, 18·9 per cent.
Heat lost by jacket water, 40·8 per cent.

Stockport Engine.—In another modification of the type of compression engine giving an explosion or *impulse every revolution*, the charge is mixed and partly compressed in a separate cylinder or chamber which feeds the motor cylinder.

Messrs. J. E. H. Andrew and Company, of Reddish, near Stockport, the makers of the Bisschop engine since 1878, brought out an important engine (Andrew's patent), called the "STOCKPORT," in the year 1882, and ceased to make it about the end of 1891. The original type was modified by experience, and several thousands of these engines were built and sold in Great Britain.

In the early form, Fig. 115, the pump cylinder is fixed opposite the motor cylinder on the same axis, so that the piston is a double trunk with the crank-shaft between the cylinders. The two cylinders communicate with each other by a chamber in the base of casting. The charge of gas and air is drawn in through a slide valve, the admission being controlled by a governor. The pump cylinder draws in the mixture, compresses it, and supplies the motor cylinder every revolution. Towards the end of the explosion stroke the motor piston uncovers the exhaust port, and the residual ducts are rejected before the incoming charge, which is further compressed by the motor piston before being
Here obviously one of two things, if not both, must
: either part of the charge of gas and air escapes with the

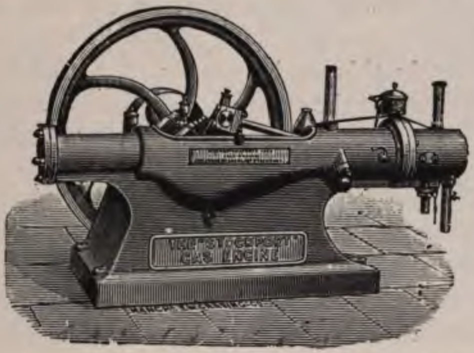

FIG. 115.—EARLY STOCKPORT ENGINE, 1882.

burnt products by the exhaust, or else a considerable portion of these products is retained in the cylinder with the fresh charge. Hence, unless the engine is very carefully made to the proper proportions, there is likely to be waste of gas to the exhaust, and consequently the gas consumption will be high.

The ordinary slide valve, with flame from a constant burner outside, was sometimes used to fire the charge. Since 1888 the ordinary *mode of ignition* is by hot tube made of a special metal, mainly nickel, which lasts several months under ordinary working conditions. This special metal tube removed one great drawback to this mode of ignition, namely the frequent renewal of the tube. A chimney and hood were arranged around the tube, to regulate the draught and keep up a constant temperature in the tube, which tends to longevity.

The action in this engine differs from that in the Clerk, mainly in the use of the scavenger charge of air by the latter, which is probably sacrificed in the Stockport at the expense of some gas.

The *double-acting type* had two motor cylinders placed end to end, with their piston rods attached to a common crank pin on the main shaft, as shown in Fig. 116. The same is true of the pump cylinders placed *below and parallel to* the motor cylinders which they supply. By this means two impulses are given to the driving shaft every revolution, that is, one explosion at every piston stroke or half-revolution except when the governor acts, and with a suitable fly-wheel great steadiness in running is obtained.

An improved form of this double-acting type was also introduced. This consists really of two independent engines with their motor cylinders placed in a line opposite one another, and the charging cylinders arranged in the same way, each underneath the cylinder it supplies. With full load this device secures two impulses every revolution of the crank-shaft, and consequently steady, regular running. The mechanism is so arranged that the pair of cylinders at either end may be thrown out of action, and the other pair run alone when the load is light.

This design of engine with the cylinders end to end was abandoned by Messrs. Andrew for several reasons. The thrust on one of the cylinders was at the top of the liner instead of at the bottom. This tended to lift the engine off its foundation, and caused a peculiar rocking motion of the engine. In order to allow for expansion by heat in gas engines the piston must be left slightly slack, and this caused a knock in the cylinder where the thrust was upward, because during compression the connecting rod was forcing the piston against the bottom of the cylinder, but immediately the ignition took place the piston was then pushed up against the top of the cylinder. Another trouble was in the crank pin wearing oval and overheating, requiring special attention to keep it cool. Notwithstanding these mechanical difficulties, this design has been followed by both Messrs. Andrew and Crossley in their large girder frame pattern of double-cylinder engines. A plate was fixed inside the cylinder at the top to reduce the knock due to the upward thrust.

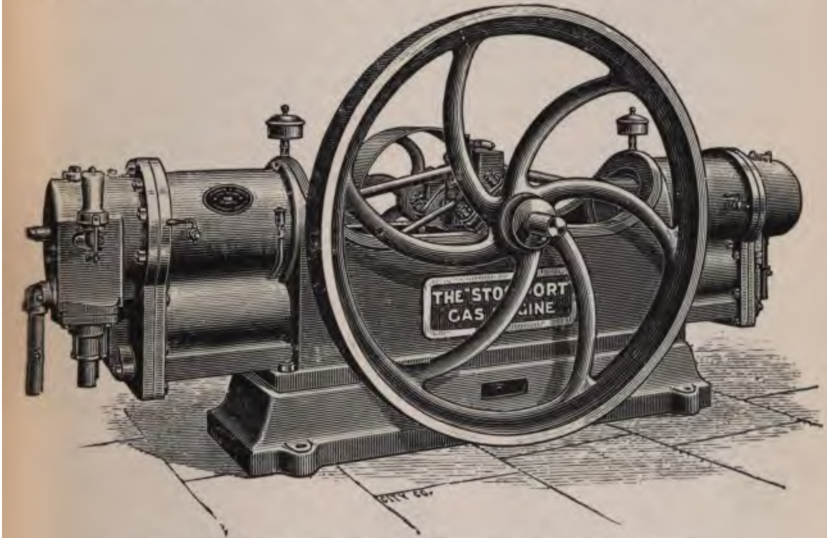

FIG. 116.—IMPROVED DOUBLE-ACTING STOCKPORT ENGINE.

A *small vertical Stockport engine* was also made for very small powers up to $\frac{3}{4}$ horse-power.

In this design the one piston is different in diameter at its two ends, and serves not only to draw in and compress the charge, but also to receive the working impulse. The upper part of the piston, travelling to and fro in the charging cylinder, is larger in diameter than the lower part, which fits the small motor cylinder at the bottom of the column. The mixture of gas and air is drawn into the cylinder by the charging end of the piston, and thence forced down by it through the non-return valve into an annular space around the top of the motor cylinder, into the lower part of which it is compressed in the usual way before ignition. The charge is fired by a heated tube. There is no slide valve in the engine.

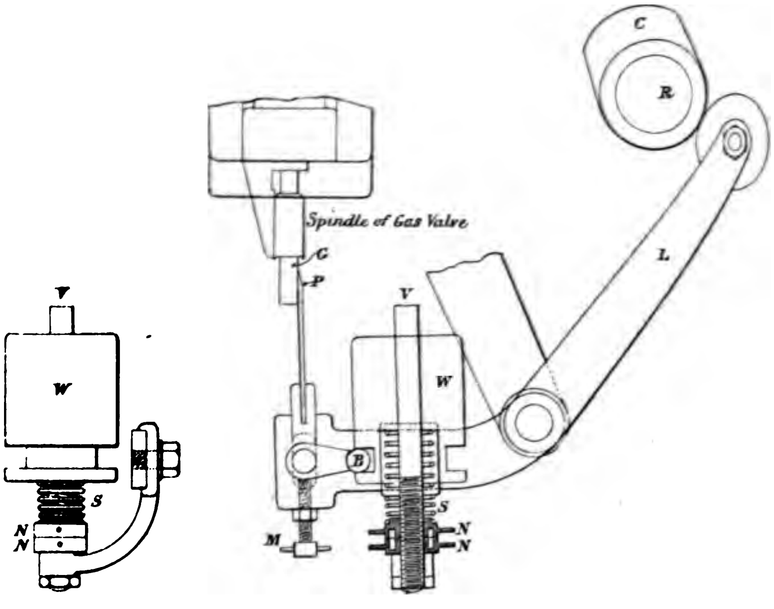

FIG. 117.—STOCKPORT VIBRATING GOVERNOR.

The speed of the smaller Stockport engines is still admirably regulated by a simple and sensitive form of **vibrating governor**, which opens or closes the charging valve, admitting and cutting off both gas and air, to keep the speed steady.

The "Stockport" vibrating governor, Fig. 117, consists of a weight W riding on a spring S, and free to move about a vertical spindle V. A groove in this weight engages the bell-crank lever B and tilts the pecker P, which hits or misses the gas-valve spindle G. The position of the weight W thus determines whether the pecker P will engage the spindle of the gas-inlet valve when pushed up by the vibrating lever L worked from the side shaft R by the cam C. The action of this governor does not depend on inertia alone. The resilience of the spring lifts the weight a certain distance in a given time. If the time is reduced, by the speed of the engine increasing, the spring cannot lift the weight so far in the shorter space of time ; and the weight being in a lower position compressing the spring, moves with it the bell-crank lever B, and so tilts the pecker P that it misses the spindle when raised by the lever L when the cam C comes round and the gas is cut off, or not admitted.

The speed can be readily adjusted at any time whilst the engine is running, by tightening or slackening the spring by means of the thumb-screw and lock-nut N, N. The pecker P can also be raised or lowered in the slot by the set-screw M. This vibrating governor is very simple, sensitive and reliable, and has been largely used on the Stockport engines up to the present time.

In the year 1888 Messrs. Andrew took out a patent (No. 10462) for governing their engine by altering the quantity of explosive mixture of gas and air drawn into the cylinder. This was done by raising the charging slide valve a greater or less amount. The proportion of gas and air remained the same, but the quantity of the mixture in a charge varied according to the load on the engine.

CHAPTER IX.

MODERN GAS ENGINES.

Modern Stockport.—The Otto cycle engines now built by Messrs. Andrew and Company, of Reddish, near Stockport, are well designed and carefully constructed.

Fig. 118 is a view of the general type of the modern "Stockport" gas engine for small powers, and electric lighting from 2 to 18 effective horse-power. The cylinder frame sits upon a separate foundation plate. The side shaft is carried on the inside of the frame, and the worm-gear wheels

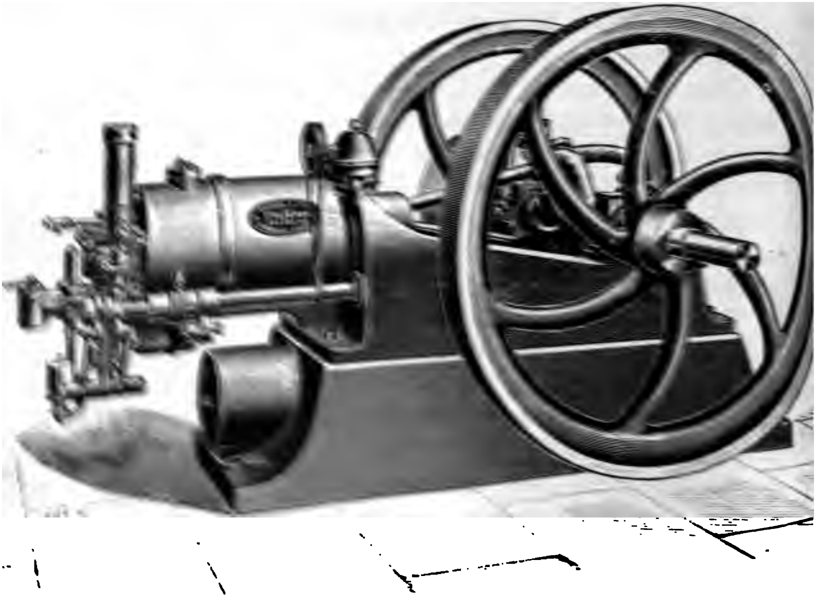

FIG. 118. MODERN STOCKPORT ENGINE, 2-18 BRAKE HORSE-POWER.

are fixed between the crank and the main bearings. This enables the two fly-wheels to be put close up against the main bearings, and consequently there is left less overhang than there would be if the wheels were on the outside of the bearings. Besides, this position of the scroll wheels makes the frame of the engine wider and consequently with a wider foundation. The cylindric portion of the base is the air-silencing chamber fitted with baffle-plates, and cast as a separate compartment in the base-plate. The idea is to silence the air suction and prevent any possible chance of gas getting down to cause explosions shattering the base-plate.

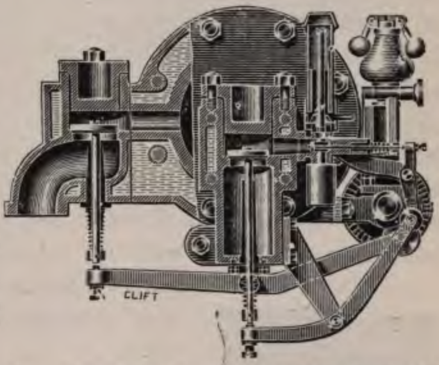

FIG. 119.—MODERN STOCKPORT (SECTIONAL END ELEVATION).

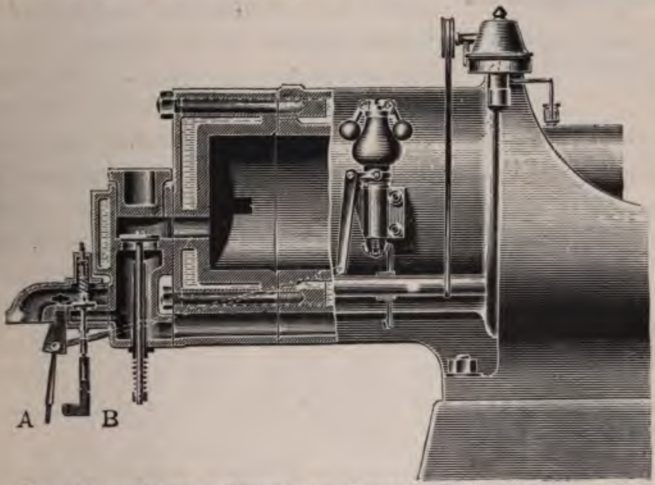

FIG. 120.—MODERN STOCKPORT (SECTIONAL SIDE ELEVATION).

In the large sizes the air quietening chamber is entirely separate from the engine.

Another main feature in the design is that the *cylinder* is well supported and cast in one piece with the frame. The back cover or combustion chamber being bolted on the end of the cylinder, enables this part to be got at for cleaning or repairs more readily than by having the cylinder loose. Fig. 120 is a side elevation, part in section, of the cylinder and combustion chamber through the air and gas admission valves, showing how the cylinder end is bolted to the main casting. The charging valve is next to the combustion chamber. Fig. 119 is an end elevation looking on the back cover, with a section showing the ignition timing valve, air admission valve, and exhaust valve to the left, held on their seats by springs, and operated by levers from cams on the side shaft seen to the right.

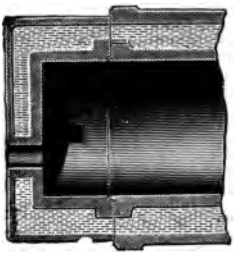

Fig. 121.—Stockport (Cylinder End).

All the *valves* used are of the conical-seated mushroom lift type, and provision is made on the valve spindles for turning the valves on their seats to ascertain whether any dirt prevents them closing tightly on their seats when pulled by the spiral springs. Except the small timing valve all the valves are vertical, being less liable to stick, and the weight of the valve helps to keep it on its seat.

Fig. 121 is a sectional side elevation of the cylinder end, with part of the cylinder showing the metal in the cylinder end thinner than in the cylinder itself, so that in the event of the water in the jacket becoming frozen it would only fracture the cylinder end, without doing any damage to the main cylinder and frame of the engine, and the cylinder end part can be easily renewed. The loose liner, made of specially hard cast iron, is fitted into the cylinder so that it can be easily removed when necessary.

Fig. 120 shows a *centrifugal governor*, which first throttles the supply of gas and then, on the speed still rising, a cut-out takes place, by the action of the trigger A coming in contact with the bell-crank lever B which is fixed to another lever actuated by a cam similar to the other valves. This vertical form of governor is dispensed with in favour of the horizontal type, page 216, now in use.

The *bracket with timing valve* F, Fig. 122, is fixed to the engine, as shown in Fig. 119, just over the charging valve, where the explosive mixture is the purest. The lever D is actuated by a cam on the side shaft, and opens the timing valve F just about a ¼ inch before the end of the inward stroke of the piston. The rich mixture of gas and air passes by the timing valve F up through the small inner tube into the ignition tube G, which is kept at a bright red heat by the circular Bunsen burner H. Any products of combustion which remain in the tube G from the previous explosion are driven out of the tube by the fresh charge, and rush down through the annular passage between the inner and outer tubes into the small chamber above the small starting valve A. The fresh explosive mixture of gas and air is ignited in the tube G,

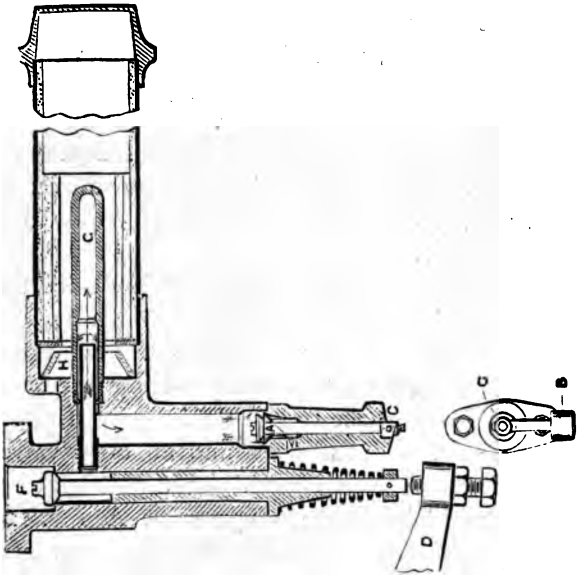

FIG. 122.—STOCKPORT (TIMING VALVE, IGNITION TUBE AND STARTING VALVE).

and the flame strikes back past F and fires the charge in the cylinder. The timing valve F is held open long enough to allow the residual gases in the igniter to be drawn out and discharged through the exhaust valve. The special advantage of this timing valve is that it is a single valve, and is only allowed to open when the engine gets on the dead centre, thus preventing early firing. Again, there is no escape from the timing valve into the atmosphere, since the residual gases in the tube and passages exhaust into the cylinder.

The large sizes of engines are fitted with a double tube timing valve bracket, with duplicate timing valves, ignition tubes and chimneys complete, having one common passage leading to the combustion chamber. In the event of the one ignition tube in action breaking when the engine is running, a small knuckle lever can be instantly thrown over to engage the cam with the other timing valve, and so avoid any stoppage of the engine.

Stockport Self-Starter.—By a simple device the engine starts itself by firing the charge in the cylinder at *low pressure*, as soon as the explosive mixture is formed. The Bunsen burner is lit to bring the ignition tube to a good bright red heat. The engine crank is set at the top on the impulse stroke, with the ignition timing valve F full open and all other valves closed. The roller on the exhaust lever is put in position to gear with the relief cam. The small escape valve A, Fig. 122, on the self-starter is opened by placing the small automatic drop lever B C in the notches marked " to start."

When the gas is turned on slightly to the starting inlet valve, the gas flows into the cylinder, displaces and mixes with the air therein, which escapes in the direction of the arrows through the inner ignition tube, then down between the tubes and out through the small valve A to the atmosphere. In about two minutes the mixture is ignited by the hot tube, and the flame strikes back into the cylinder and fires the charge. After the engine has made 4 to 6 revolutions, the gas bag is filled and the starting valve closed on the ignition bracket by turning over the weighted lever B C against the inclined plane. The roller on the exhaust lever is moved to gear with the single part of cam, and the engine is in full running order. This starting gear is simple and effective in everyday work.

On the valve diagram, Fig. 123, the circle represents the path of the crank pin, and the various positions of the crank show the *setting of the valves* in the Stockport gas engine for the four operations of the Beau de Rochas cycle. About 30° before the close of the exhaust stroke the air valve is opened to admit the *scavenging* air through the combustion chamber, to sweep out the burnt gases into the exhaust pipe before the charge of gas is drawn into the cylinder.

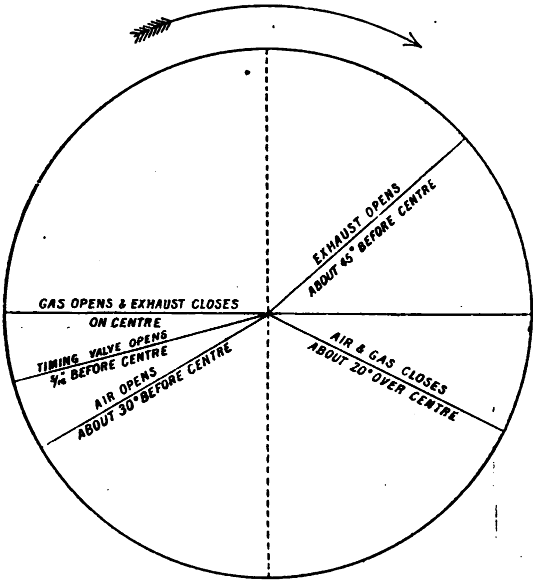

FIG. 123.—DIAGRAM SHOWING SETTING OF VALVES.

Fig. 124 shows an end view, and Fig. 125 a plan of the Stockport engine cylinder showing the ***horizontal centrifugal governor.*** It is difficult to drive the vertical centrifugal governor satisfactorily by bevel gear, when the small pinion on the governor shaft gets worn. With the horizontal governor ordinary spur wheels are used which give no trouble, and therefore the sensitiveness of the governor is longer maintained. Apart from this the horizontal type of centrifugal governor suits the engine better, as the levers and connections are shorter, with more direct action. The Stockport governor acts upon the end of the lever which lifts the gas valve, Fig. 120, page 211. At the end of this lever there is a small bell crank, and the governor moves a rod to engage with the latter, moving it on one side, so that when the cam comes

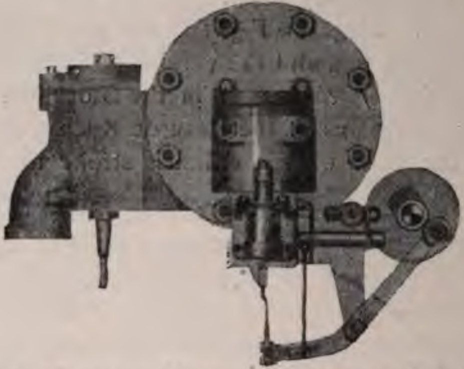

FIG. 124.—STOCKPORT HORIZONTAL GOVERNOR (END VIEW).

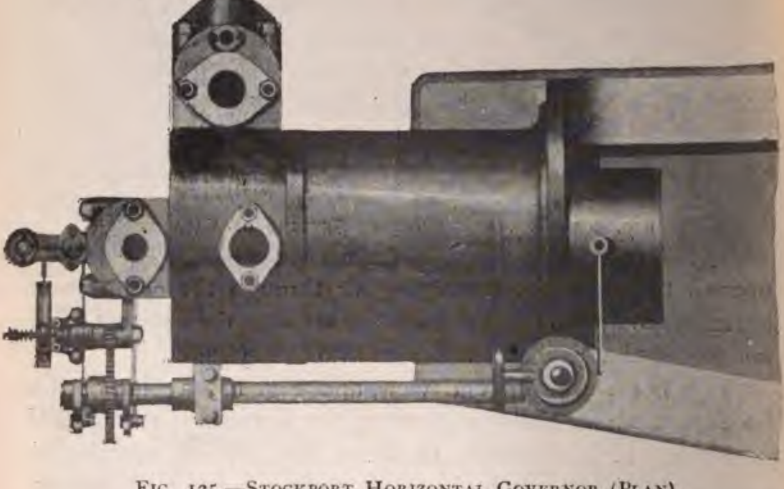

FIG. 125.—STOCKPORT HORIZONTAL GOVERNOR (PLAN).

round and lifts the lever for operating the gas valve, the striking end or pecker has been turned out of the way and the gas valve is not moved or opened, and consequently no gas enters the cylinder. By this action there can be no half charges—all or none being admitted. By means of a few notches on the end of the valve spindle, this governor can regulate by a throttle valve the amount of gas passing into the cylinder, that is to say, varying the amount of gas before making the cut-out. The same throttle can be made to regulate the quantity of air, so that the governor can be used not only for hit-and-miss, but also to throttle the gas ; that is, to reduce the *quality* of the mixture, or to throttle both the gas and air, and so reduce the *quantity* of the charge. The speed of the engine can be changed by tightening or loosening nuts against the spring whilst the engine is running.

In the *trunk frame* engine, Fig. 126, sizes 50 to 120 brake horse-power, the cylinder and main frame are bolted straight to the foundation. In the larger engines of this type the cast-iron base-plate is dispensed with, so as to keep the centre line in the engine low, and have a firm grip on the foundation. The bed is extended under the cylinder, which is well supported. The exhaust valve box is cast as part of the cylinder end, thus saving the joint. Two engines of this type using Dowson gas in a factory at Edenderry, Portadown, were tested by Mr. Hamilton Robb, during a run of three days of average twelve hours each, in July 1898. One engine gave 69 indicated horse-power at 138 revolutions per minute, and the other 49·5 indicated horse-power at 134 revolutions per minute, the mean effective pressure being 85 lb. per square inch. Both engines were running under half power, and yet the consumption of anthracite coal came out at 0·78 lb. per indicated horse-power hour. These engines would work on a consumption of 15·5 cubic feet per indicated horse-power hour with ordinary coal gas.

The design, Figs. 127 and 128, of the larger Stockport engine is somewhat on the lines of good, mechanically built steam engines. The cylinder and main bearings are bolted to a *flat frame* bed to avoid overhanging of the cylinder.

The piston has a cross-head and outside slide block to take the thrust of the connecting rod off the piston and so decrease

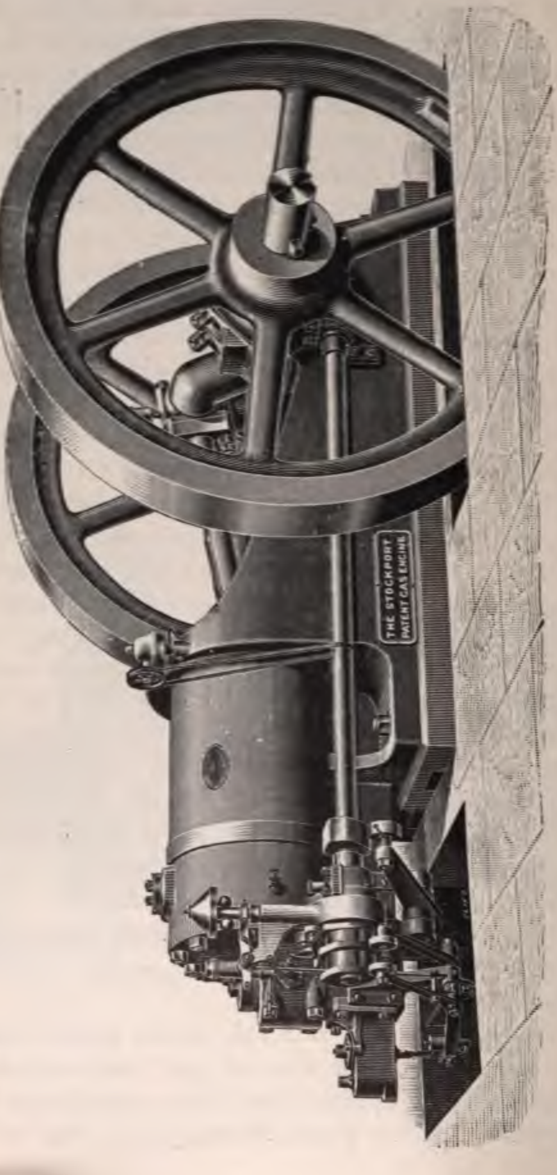

FIG. 126.—MODERN STOCKPORT, 50-120 BRAKE HORSE-POWER.

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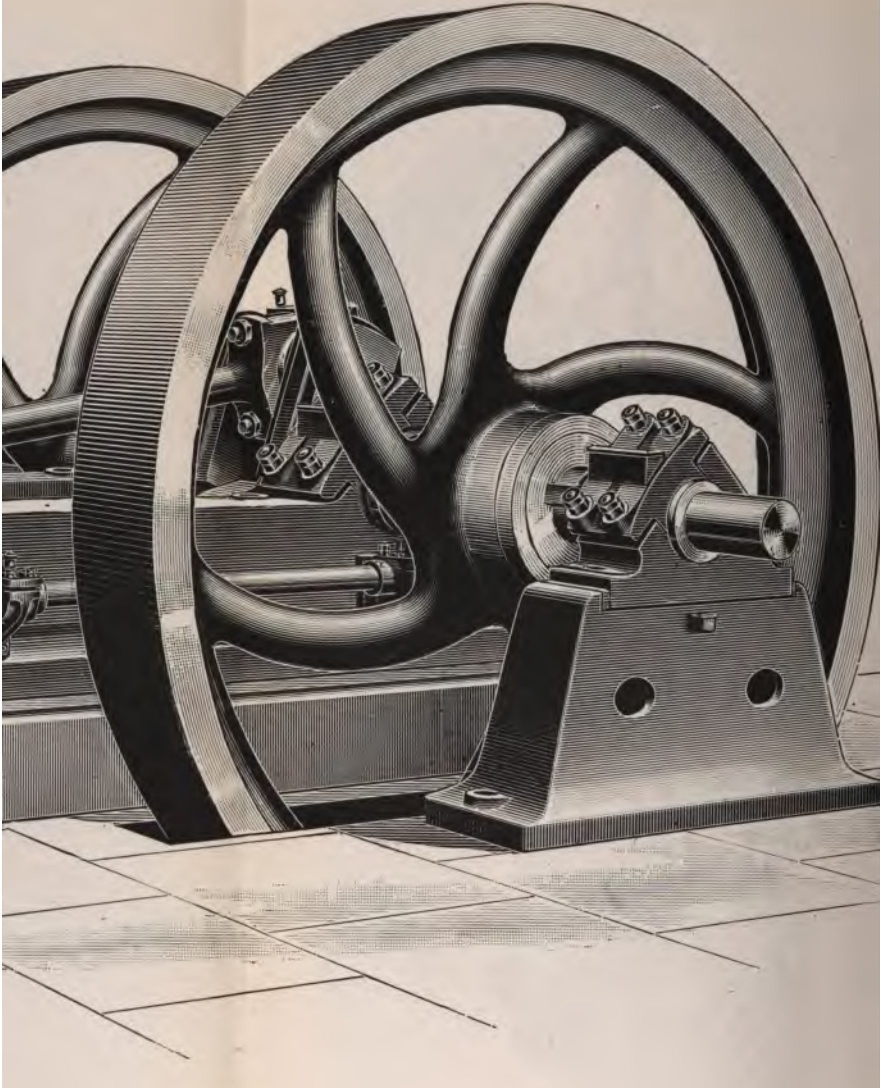

-POWER.

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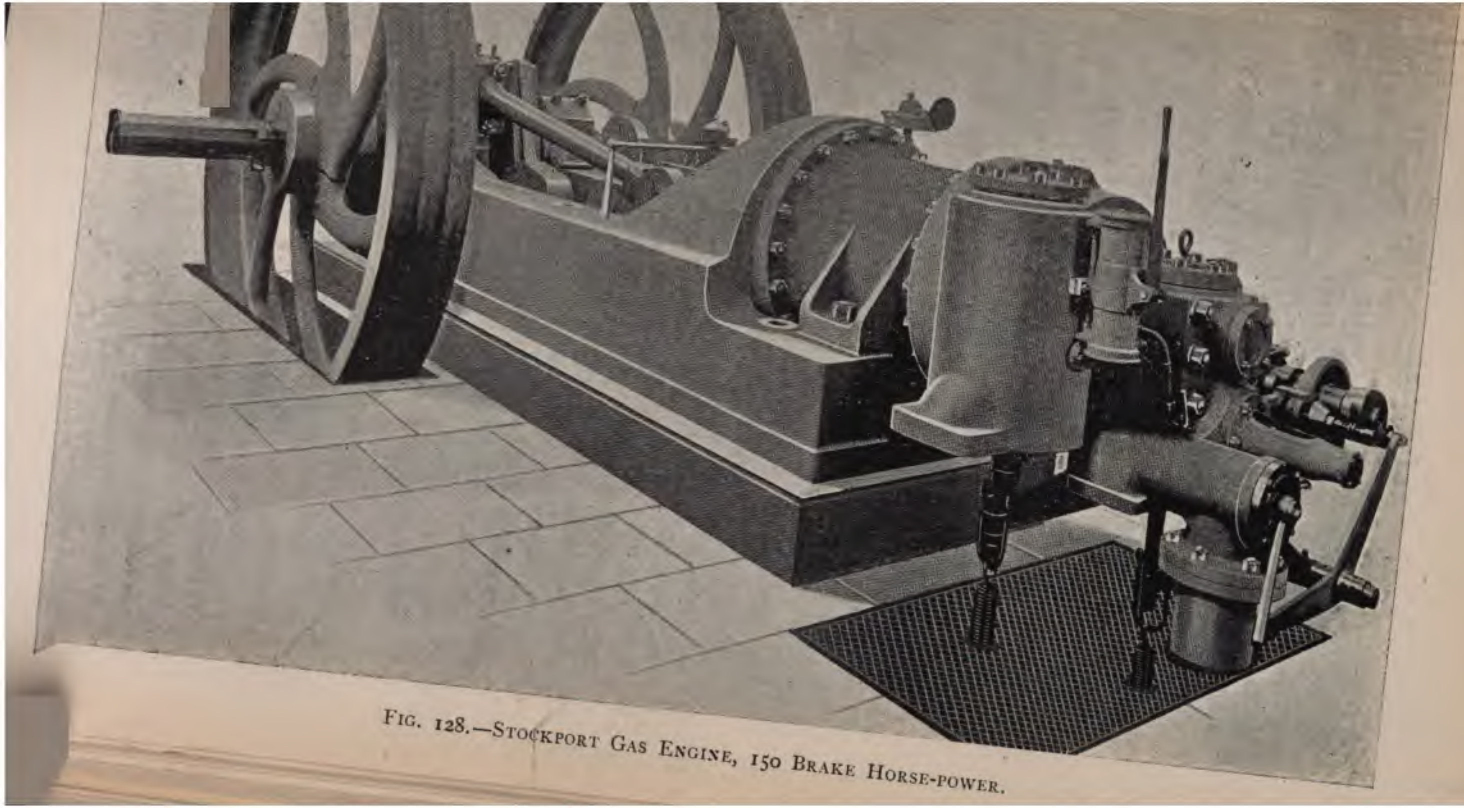

FIG. 128.—STOCKPORT GAS ENGINE, 150 BRAKE HORSE-POWER.

the wear and tear. The crank-shaft is balanced by cast-iron blocks strapped on the crank webs. The cylinder end is loose, so that it can be taken off for cleaning the water-jacket, &c., without disturbing the cylinder. The engine can be changed from using coal gas to producer gas by merely turning the gas supply valve to a different position.

The cam shaft is carried outside the frame, but an outside bearing is arranged for the crank-shaft. The engine is fitted with the double ignition tube bracket, and pump starter.

The engine, having cylinder of diameter 20 inches and the stroke 30 inches, running at 160 revolutions per minute, develops with coal gas a maximum of 150 brake horse-power, and with producer gas about 125 brake horse-power. Each fly-wheel is 10 feet diameter by 15 inches wide on face, and weighs 6 tons. The diameter of the crank-shaft is 9 inches at main bearings, which are 16 inches in length.

Where greater power is required, in a small space, the old Stockport design of two cylinders end to end, and working on the Otto cycle, may be adopted, as in Figs. 129 and 130. The disadvantages of this type of engine (see page 207), are reduced by making a very long piston, and a very large crank pin attached to the connecting rods, as shown in Figs. 129 and 130. It is impossible in this way to get an explosion each revolution and very heavy fly-wheels are necessary to obtain uniform speed. The cam shaft for both cylinders is on one side, so as to keep the other side free for the attendant to get at the motion work. This means that the cylinder ends and valve boxes have to be made right and left-handed, which adds to the expense of construction.

Indicator Diagrams and Gas Consumption.—The indicator diagram, Fig. 131, taken from a Stockport gas engine using coal gas, shows 12 consecutive explosions. The engine cylinder was 19 inches diameter, the stroke of piston 26 inches, the speed 160 revolutions per minute, and there were 75 explosions per minute. The light spring diagrams, Fig. 132, indicate the pressure during the pumping strokes, exhaust and charging, when the governor is cutting off gas, only air being admitted, also when both gas and air are

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tted. Fig. 133 indicates the pressure when working with son gas. It is usual to allow a compression before ion, from 80 to 90 lb. per square inch with coal gas, and 95 to 100 lb. with Dowson or other cheap fuel gas.

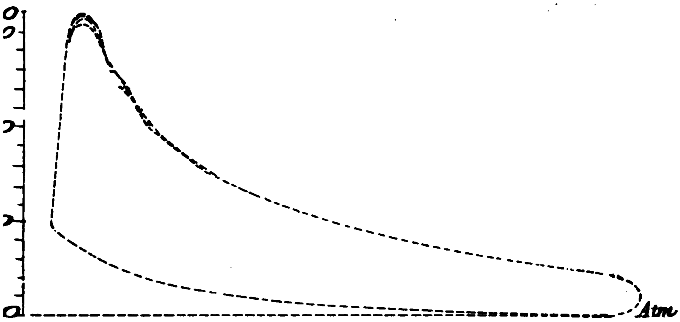

FIG. 131.—INDICATOR DIAGRAM : STOCKPORT WITH COAL GAS.

r. G. P. Mills has supplied the author with details of *tests* made by him on Stockport gas engines at the gh Cycle Factory, Nottingham, in February 1898. In

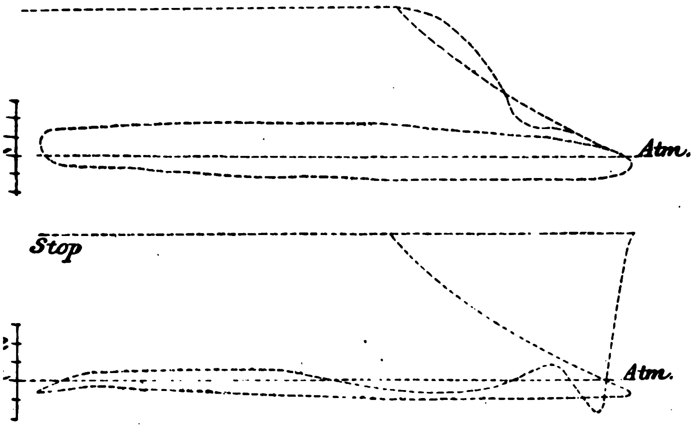

FIG. 132.—LIGHT SPRING DIAGRAMS OF PUMPING STROKES.

of the engines the cylinder was 15 inches in diameter the stroke of piston 22 inches, each giving 65 brake e-power at 160 revolutions per minute, with ordinary gas at the rate of 16·5 cubic feet per brake horse-power per hour. These engines were supposed to give 59 brake horse-power, and were tested in the evening after running all day without any special preparation whatever. The smallest engine gave 8 brake horse-power at the rate of 28·5 cubic feet of town gas per brake horse-power hour.

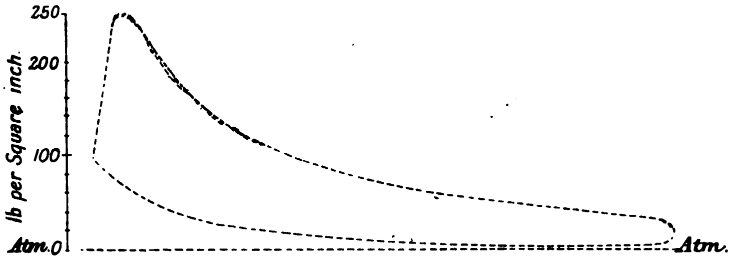

FIG. 133.—INDICATOR DIAGRAM. STOCKPORT WITH DOWSON GAS.

A 30 effective horse-power Stockport gas engine driving a dynamo for electric lighting in the Belfast Exhibition of 1895, was tested by Mr. V. A. H. McCowen. The load of incandescent lamps was put on until the engine appeared to be nearly fully loaded, and then kept steady within 2 per cent. during the half-hour test. Readings were taken every 5 minutes, and the electrical instruments were afterwards calibrated by a potentiometer. Running at a mean speed of 189

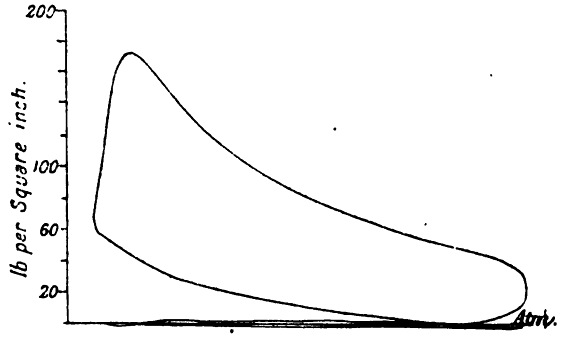

FIG. 134.—INDICATOR DIAGRAM. STOCKPORT GAS ENGINE.

Mean effective pressure 73·6 lb. per square inch; 87·5 explosions per minute; 190 revolutions per minute; and 33·96 indicated horse-power.

revolutions per minute, the engine gave 33·96 indicated horse-power, and the output at the dynamo terminals was 22·27 electrical horse-power. The brake horse-power 28·33 was taken as equal to the indicated horse-power at full load less that at no load. Indicator diagram, Fig. 134, shows the pressure of gases in the cylinder. The gas consumption was 18·4 cubic feet per indicated horse-power hour, and 28·1 cubic feet per electrical horse-power hour. The heating value of the gas was found by Junkers calorimeter to be 550 British thermal units per cubic foot. This poor gas consists of partly enriched or carburetted water gas.

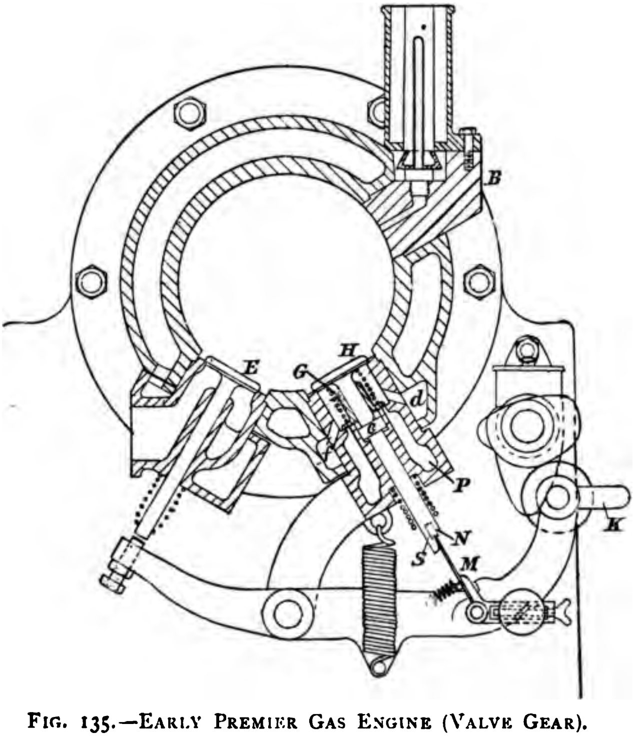

FIG. 135.—EARLY PREMIER GAS ENGINE (VALVE GEAR).

The Premier Gas Engine, formerly built by Messrs. WELLS BROTHERS, and now by the PREMIER GAS ENGINE COMPANY, of Sandiacre, near Nottingham, is a well designed engine, with several novel and interesting features. The smaller engines, from 1 to 6 brake horse-power, patent No. 16,434 of 1889, of Messrs. HAMILTON AND ROLLASON, are of the ordinary four-stroke type, with cam shaft inside the bed or frame, and the combustion chamber spherical in shape, with the valves opening radially into that space, as seen in the cross section Fig. 135. In this way the valves break up the combustion chamber as little as possible, and there is the least possible cooling surface for a given volume.

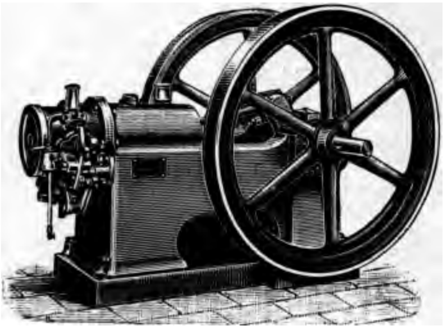

FIG. 136.—12 HORSE-POWER NOMINAL PREMIER GAS ENGINE.

The Air and Gas Admission Valve (patent No. 4189 of 1892), designed by Mr. J. H. Hamilton, B.Sc., is a special feature of the early Premier engines. The gas valve G is made a loose sliding fit on the spindle, and covers the annular port leading to the gas supply passage P. The air enters from a silencing box in the bed-plate through the space *d* and ports *f*. In opening the valve only air is admitted at first when the outer spring is pressed. On the further inward motion of the spindle, a collar *c* on it engages the gas valve G, compresses the inner spring, and admits the gas from P, which flows up in a fine stream and exposes a large surface to the air entering from *d*, now partly throttled by the gas valve. This air mixes with the gas below the head of the admission valve. As the admission valve closes the gas is shut off first, and air only is admitted towards the end of the stroke, so that the cylinder is completely filled with the charge.

In Fig. 135, M is the *inertia governor* with speed adjustment consisting of a screw for shifting the weight along the horizontal arm. The hardened steel plate S is let into the admission valve spindle, which is cut away to form notch N, or a stepped block. The governor controls the supply by moving the push piece to engage either notch on the spindle to slightly reduce the charge before cutting out the gas altogether, when only air is admitted until the speed is reduced to the normal.

The handle K is for easing the compression at starting, by partly opening the exhaust valve E. B is a block carrying the ignition tube, with Bunsen burner and chimney. This block is ground to its seat and held in place by two nuts, and can be easily taken off and replaced, when either the admission or exhaust valve may be withdrawn for cleaning or inspection. There are three bearings for the crank-shaft, one being divided

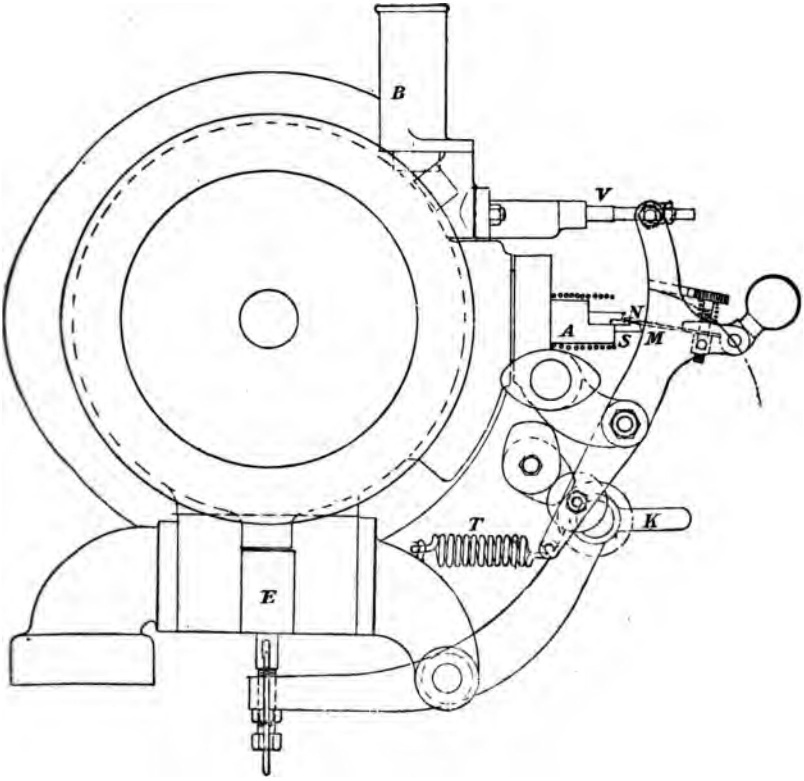

FIG. 137.—12 HORSE-POWER PREMIER GAS ENGINE (END ELEVATION).

by the skew gear to drive the cam shaft, which lies inside the bed or frame of the engine.

Fig. 136 is the 12 horse-power nominal engine, giving about 20 effective horse-power. This type is made in sizes from 8 to 60 effective horse-power. The design is simple, compact and substantial. The end elevation, Fig. 137, shows the inertia governor M and the admission valve A on the side of the cylinder, and the exhaust valve E below and vertical. V is the timing valve for the hot ignition tube in B. The novelty is in working the timing valve from the same lever as the gas and air admission valve. A spiral spring T, acting on the lower end of the lever, pulls the timing valve V out of its seat at the proper point in the cycle, and keeps the roller of the lever always pressing tightly against the cam on the side shaft which works it.

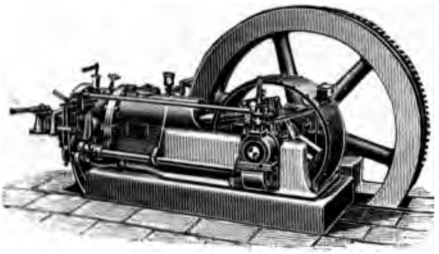

FIG. 138.—PREMIER OTTO CYCLE ENGINE, 60 AND 85 HORSE-POWER (WITH DOWSON GAS).

Some Premier engines are made on the ordinary Otto cycle, to give up to 60 and 85 effective horse-power with Dowson or other cheap fuel gas. An engine with cylinder 16 inches diameter by 22 inches stroke develops 60 brake horse-power at 220 revolutions per minute. This type, Fig. 138, may be used to drive dynamos, as at the Leyton electric lighting station. The valve gear is like that in Fig. 139. There is a fine adjustment to the timing valve by a screw on the end of the spindle. This plan permits a good large roller on the cam, as only one is required. In all Premier gas engines the exhaust valve is below the cylinder and vertical. There is an independent and continuous oil feed by centrifugal force to the pin of the governor balls, where the pressure is greatest. A dripper carries oil to little passages in the hollow cup-like rim, and then it is forced against the governor pin.

The *centrifugal governor*, A, Fig. 139, is driven direct from the crank-shaft by bevel gear. The motion is transmitted to the push piece M by a horizontal spindle having an arm keyed on it at each end. The arm L at the cylinder end has a sliding block to which a spring C is attached. The block is moved along the lever by a screw and handle. This arrangement gives a very fine adjustment of speed while the engine is

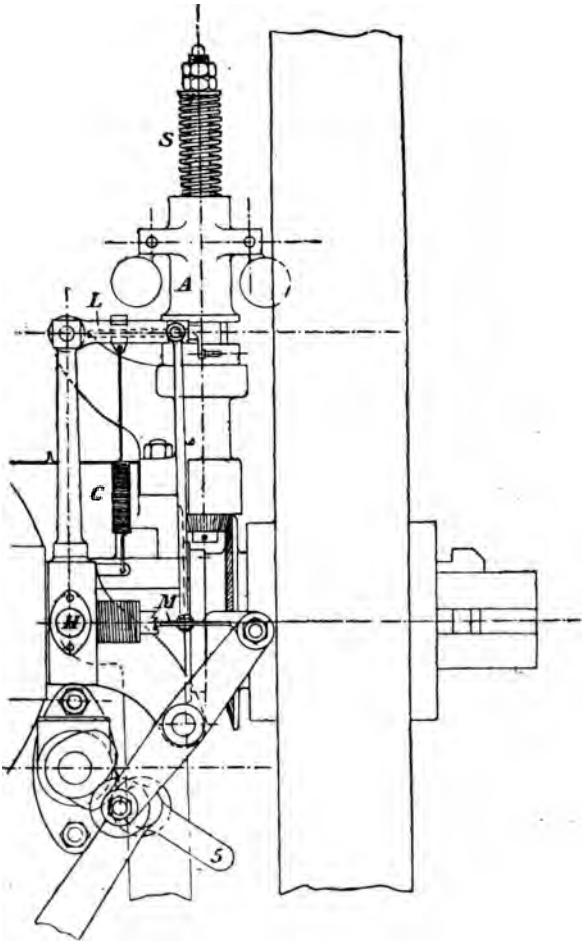

FIG. 139.—PREMIER ELECTRIC LIGHT GOVERNOR GEAR.

running, but is only used for a range of about 10 per cent. The main resistance to the centrifugal force of the balls is supplied by the strong spring S above the governor. The use of the oscillating spindle turning about its axis allows of a quick action, because its moment of inertia is small, and its angular motion not more than 4°. A long rod, moved as a whole in the direction of its length, could not act so well in a high speed engine, because of its great inertia and considerable motion. With the object of getting a quick action all the parts of the governor and its connections, which receive their motion from the rise and fall of the balls, are made as light as possible, while the high speed renders the use of a strong spring necessary. Thus the ratio of force to mass is great, and as a very small movement is required for a cut-out by the push piece M missing the spindle of the gas admission valve H, the action is extremely quick.

The *starting gear* consists of a winch handle with pinion engaging in the teeth of the rack around the rim of the fly-wheel, Fig. 138, to turn the crank into starting position. Then slide the pinion out of gear with the rack. A hand pump at the end of the cylinder is used to force a charge of gas and air into the combustion chamber. When the fly-wheel is on the point of starting, release the catch holding the timing valve closed, and the compressed charge is fired by the hot tube. An engine can be started within 4 or 5 minutes after lighting the ignition tube burner. When working with Dowson gas the compression of charge before ignition is from 70 to 90 lb. per square inch, and the pressure at explosion from 250 to 300 lb. per square inch, giving a mean effective pressure about 75 to 80 lb. per square inch.

For *electric lighting* a marine type short stroke engine, working on the Otto cycle, is built of 15 and 50 brake horse-power at 500 revolutions per minute. The engine has two vertical cylinders close together, the pistons always moving in opposite directions with cranks placed, at 180° apart, for the *balancing* of the reciprocating parts, and enclosed in a crank chamber for perfect lubrication. The dynamo is coupled directly to the crank-shaft. In this engine *electrical* *ignition* is employed. The spark is obtained by means of a primary current, and striking or "make and break" contact between platinum points in the combustion chamber. One electrode is fixed in an insulating plug, and the moveable point is operated by mechanism outside the cylinder, which can be adjusted so that ignition takes place at the highest point of compression, or at that part of the stroke which gives the highest efficiency with the combustible mixture employed.

The Premier Positive Scavenger Engine. HAMILTON'S patent, No. 6015 of 1890, was exhibited at the Crystal Palace in 1891. This engine, Fig. 140, used only 16·7 cubic feet of London gas per indicated horse-power hour when developing 27 brake horse-power. The compression of the charge before firing was 65 lb. per square inch. The *Premier* engine appears to be the *first positive Scavenger engine* built on the ordinary Otto four-stroke cycle, and having the valve setting (page 232) afterwards adopted by Messrs. Crossley and Atkinson, except that the air valve was opened a little earlier. Fig. 141 is a longitudinal section, and Fig. 143 an end view of the single cylinder Scavenger engine. A is the motor cylinder, B the air cylinder, and C the differential piston with large end, which forms an air pump working in the bed-plate. The air is drawn in through the grid valve F into the large clearance D and the annular space in front of the piston next the crank-shaft. On the return stroke this air is compressed to about 4 lb. per square inch above atmospheric pressure. During the explosion stroke the air expands again, having gained heat from the cylinder. After half way on the exhaust stroke the air, compressed to about 2 lb. per square inch above atmospheric pressure, is discharged along the passage E, Fig. 141, and rushes past the admission valve H into the cylinder, displacing and sweeping the burnt gases completely out through the exhaust G. This scavenging takes place during the last quarter of the exhaust stroke, and while the piston is turning the centre. The exhaust valve G is held open until the crank passes the centre. The gas admission valve K opens as soon as the exhaust is closed.

The valve setting is seen by the crank pin diagram, Fig. 142.

The clearance space D is made large, about three times the volume swept by the pump piston, so that the air pressure rises only 2 to 5 lb. above atmospheric on the motor piston

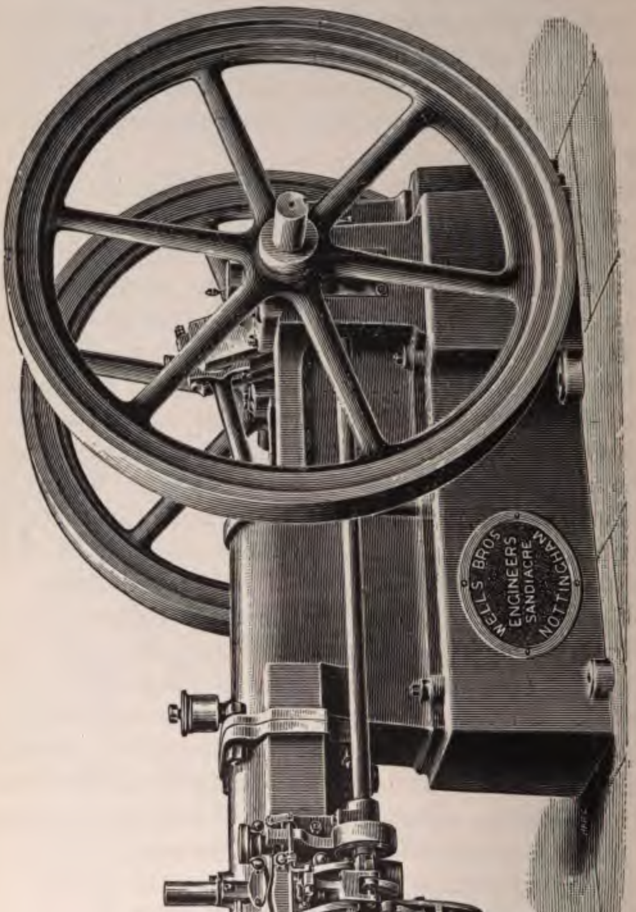

Fig. 140.—Premier Engine, First Positive Scavenger Type, 1890.

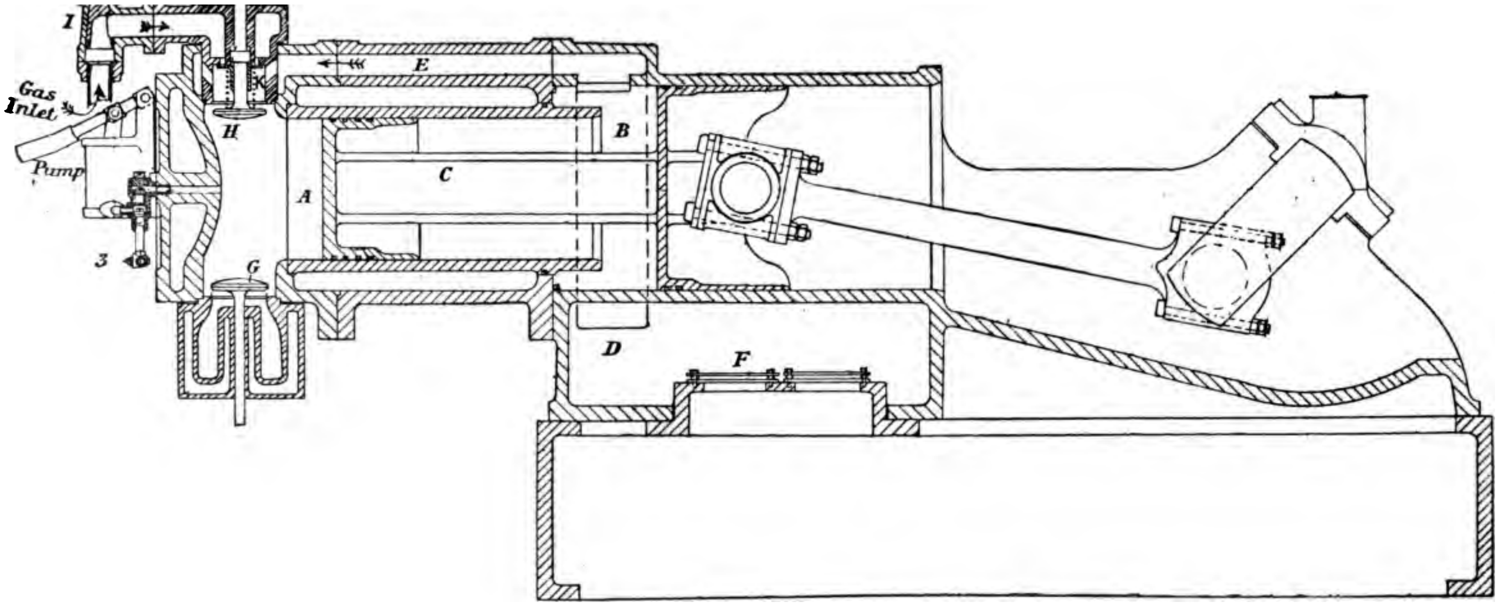

FIG. 141.—PREMIER POSITIVE SCAVENGING ENGINE (LONGITUDINAL SECTION).

compression stroke when there is no outlet for the air. The average pressure in the air pump, required to force the scavenging air through the combustion chamber into the exhaust pipe, is only 1 or 2 lb. per square inch. The air cylinder is also useful in guiding the large end of the front piston, which acts as a cross-head of large bearing surface to take the lateral thrust of the connecting rod.

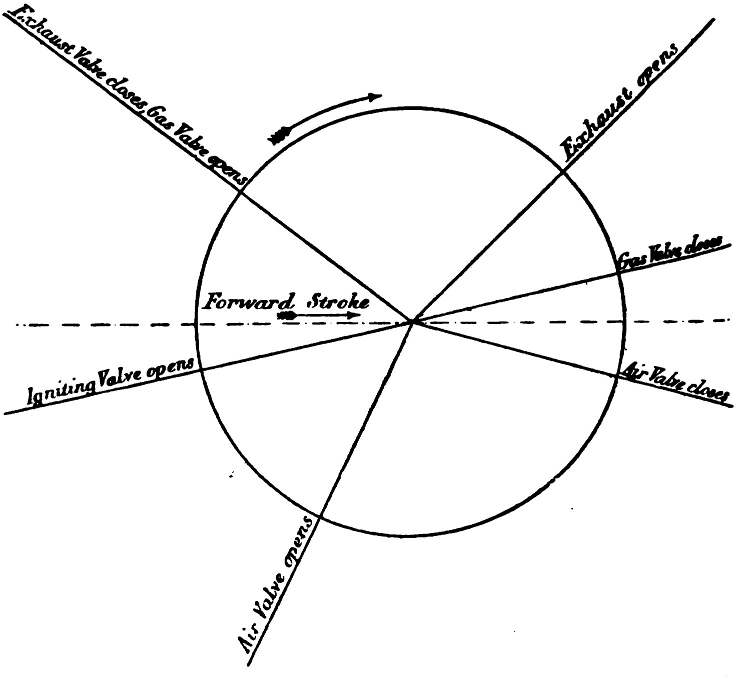

FIG. 142.—PREMIER SCAVENGER ENGINE (DIAGRAM OF VALVE SETTING).

Some important *advantages of this positive scavenging* are: (1) the surface of cylinder, ports, end of piston and valves are cooled by the scavenging air, because three times the volume of the combustion chamber of fresh air is passed through after every explosion, sweeping out the hot burnt gases ; (2) the compressed charge is purer, richer in gas, and cooler than in the ordinary Otto cycle, hence its weight is greater in proportion to the cooling wall surface, thereby reducing the loss to the water-jacket; (3) consequently the mean effective pressure is higher in the scavenger engine, and a smaller cylinder will do the same work as an ordinary Otto cycle cylinder of 20 to 25 per cent. greater volume; (4) the air is forced through in a positive manner, and a little extra resistance in the exhaust pipe or a considerable change in the speed does not perceptibly affect the working of the engine; (5) the temperature of the mixture before compression is much less, and therefore a higher compression may be used without risk of premature explosion or bringing the temperature of the charge to the igniting point; (6) back-firing of the incoming charge by the residual hot gases is prevented, since these are swept out of the cylinder; (7) explosions in the exhaust are prevented, owing to the dilution of gases in exhaust pipe by the scavenging charge of air; (8) by thoroughly mixing poor fuel gas with air alone, without any burnt products, the charge is fired with greater certainty and regularity, and miss-fires become rare, even when the quality of the gas varies considerably; (9) after cut-out of gas, there is only a slight variation in the mean pressure of the "governor card" above the ordinary one for the next explosion.

The **Self-Starter** acts as follows: The crank is turned until the piston is on the explosion stroke, about half stroke forward, and the catch 1, Fig. 143, is raised, as shown, to hold the timing valve shut. The three-way cock 3 is then turned so as to put the *hand pump* 2 in communication through its suction valve with the gas supply, and a fixed number of strokes are given by hand to the pump. The proper charge of gas is thus pumped into the combustion chamber A, Fig. 141. Next the three-way cock is turned to close the gas valve and to admit air to the pump, which is worked until the pressure in the cylinder moves the fly-wheel slightly. Then the catch 1 is pushed down to open the timing valve, and the charge in the cylinder is fired by the ordinary ignition tube, giving the first impulse. During starting the compression is eased by the handle 5, Fig. 143, which shifts the roller that operates the exhaust valve, so as to keep this valve open during the greater part of the back stroke.

The first impulse is shown at 1, on the indicator diagrams, Fig. 144, and the succeeding ones, with relieved compression, at *a*, *b*, *c*, *d*, &c., the ordinary diagram with full compression being W. The ignitions get later and later in the stroke as the speed of the engine increases, till the full compression is used. The ordinary indicator diagram has not such a high pressure at explosion as that in W, due to the low speed. This hand-pump starter is reliable, and works well.

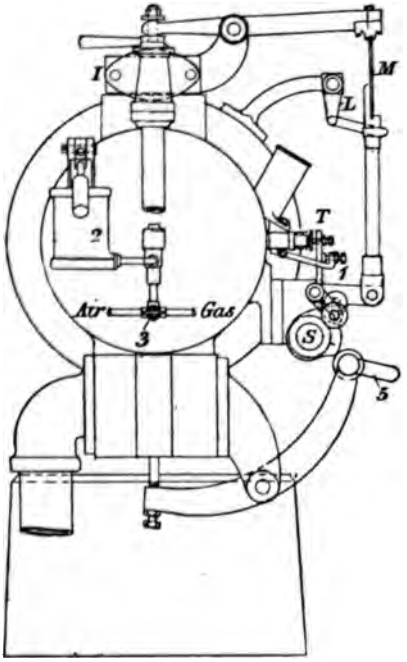

FIG. 143.—PREMIER SCAVENGING ENGINE (END VIEW).

The *centrifugal governor* is driven by bevel gear on the crank-shaft, and the motion is transmitted to the push piece M, Fig. 143, by a horizontal spindle having a crank arm L keyed to it at each end. The notches in the end of the admission valve lever give slightly different amounts of gas by varying the lift of the gas valve. . The inner notch and the outer one correspond to no gas admission. The former is merely a safety appliance, as the push piece M only engages it when the engine is running at an extremely low speed. Should the gear that drives the governor give way there is no fear of the engine racing, since the immediate drop of the governor will bring the push piece M into the inner notch, and so stop the engine. The action of the compound admission valve H in Fig. 141 is the same as described above.

The *power* of this type of single cylinder scavenger engine, having a motor cylinder 20 inches diameter by 24 inches stroke, when running continuously at 160 revolutions per minute, is 120 brake horse-power with Dowson gas. A single cylinder, 22 inches diameter by 36 inches stroke, gives 160 brake horse-power at 120 revolutions per minute with producer gas; and another size 200 brake horse-power. **In order to prevent over-heating,** the piston and exhaust valve are water-jacketed, and further cooled by the scavenging air swept through the combustion chamber after every explosion. By means of the

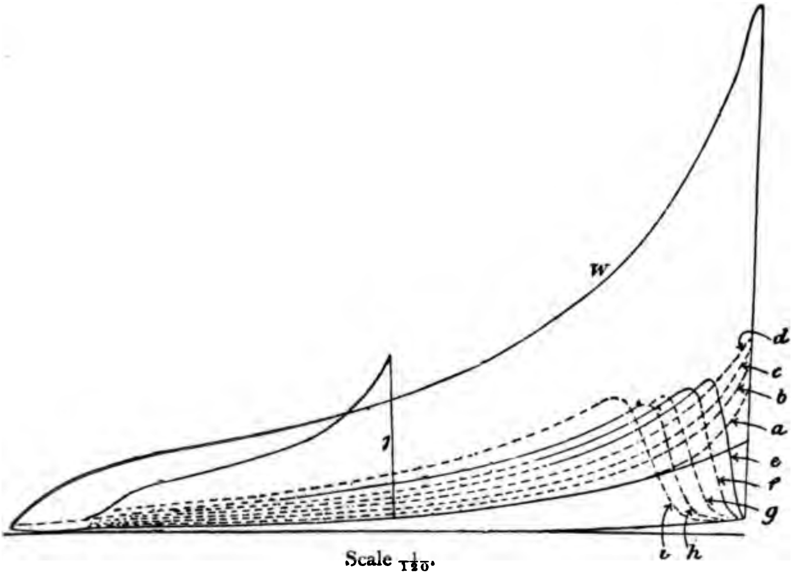

Fig. 144.—Starting Diagrams. Premier Gas Engine.

special admission valve, the cheap fuel gas and pure cool air are also thoroughly mixed, so that the charge is made homogeneous, giving prompt and certain ignition with high compression. Under everyday working conditions the charge is compressed to about 110 lb. per square inch (absolute pressure) before firing, and the mean effective pressure indicated in the motor cylinder is 90 to 110 lb. per square inch. The effective brake horse-power may be taken about 82 per cent. of the gross indicated horse-power for ordinary working.

Tandem Scavenger Engine. — The large Pr
scavenger engine has two cylinders in tandem, accordi

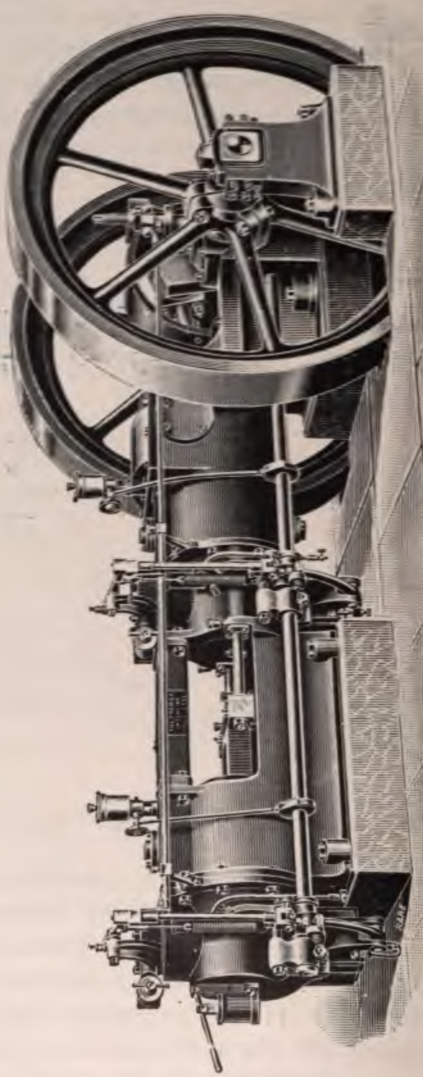

Fig. 145.—150 Horse-power Premier Gas Engine, Tandem Scavenger Type, 1893.

patent No. 24384 of 1893, as shown in Fig. 145, and in sec
elevation and plan, Figs. 146, 147, 148 and 149.

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and the pressure drops suddenly at the end of the stroke when the exhaust valve is full open. The effect of the entering air in keeping up the pressure near the end of the exhaust stroke in the motor cylinder is seen at A on the light spring diagram, Fig. 151. The dotted line gives the pressure during exhaust after a charge of gas is cut-out.

An eccentric on the crank-shaft drives a surfaced slide valve moving across grids, Figs. 149 and 152. for the admission of air to the pump, both for scavenging and charging the motor cylinders. The back piston is bolted to a cross-head and slide blocks K, Figs. 146 and 148, to which the large end of the air pump piston is attached by side rods R R through passages cast in the water-jacket. Each motor cylinder has the usual valve gear: the compound air and gas admission valve H at the top of the cylinder, the ignition tube and timing valve T, Fig. 147, and the exhaust valve G, directly under H, all operated by levers from the side shaft S. In the larger engines the pistons and exhaust valves are made hollow and water cooled, to prevent premature ignitions. At starting the first charge of gas and air is pumped into both cylinders through the valves V V, Fig. 146, by the hand pump P. The handle for easing compression is seen at 5, Fig. 147. The lubricators O O for the cylinders have a positive ratchet feed, and the crank pin is supplied by a centrifugal oiler. One of the main bearings, Fig. 148, is divided by the skew gear for the cam shaft, and outside bearings are provided with heavy fly-wheels. The governor gear, Fig. 147, is like that in Fig. 143.

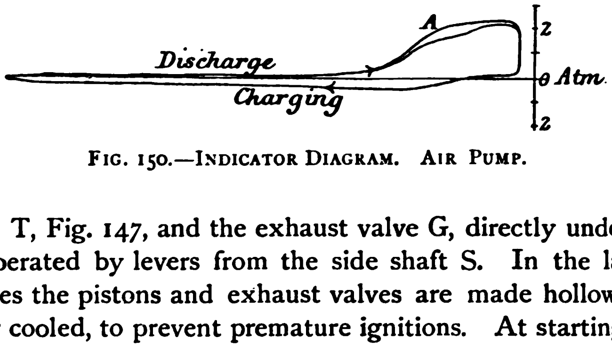


FIG. 150.—INDICATOR DIAGRAM. AIR PUMP.

Ignition is by electric spark and hot tube. Premier engines up to 8 brake horse-power use nickel tubes closed at one end, and made of 98 per cent. pure nickel. The life of these tubes varies greatly. After the first day or two, the tube may last six months or even twelve months with careful treatment. Some engines, with self starters, have nickel tubes open at both ends, with an escape cock at the top of the tube. Nickel tubes do not last well with producer gas, probably owing to the action of the sulphur compounds and carbonic oxide on the nickel at very high temperature. Hence porcelain ignition tubes are used, open at both ends, held against asbestos washers, and with an extension of cast-iron tube above the porcelain.

The design of the tandem Premier engine and the positive scavenger action make it admirably adapted to work with cheap fuel gas and for large powers. Several of these engines are at work, developing 150 brake horse-power at 140 revolutions per minute with producer gas.

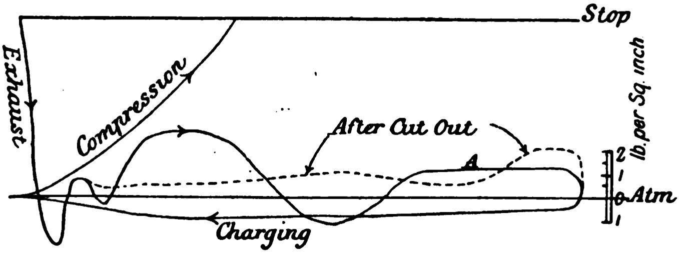


FIG. 151.—LIGHT SPRING INDICATOR DIAGRAM. MOTOR CYLINDER.

A large Premier tandem gas engine, Fig. 152, motor cylinders 28⅛ inches in diameter by 30 inches stroke, gives 489 indicated horse-power at 128 revolutions per minute with Mond gas, and runs day and night at ⅔ load of 368 brake horse-power. The average output of the dynamo is 255·4 kilowatts. The engine has one fly-wheel, 12½ feet in diameter, cast in halves; and the rim, 36 inches wide on the face, weighs 24 tons. The crank-shaft is *balanced* by weights dovetailed and strapped to the crank webs, and the end of the shaft carrying the fly-wheel and coupled direct to a dynamo for electro-plating, is supported by an outer bearing lined with white metal.

The exhaust valve and piston in each cylinder are kept cool

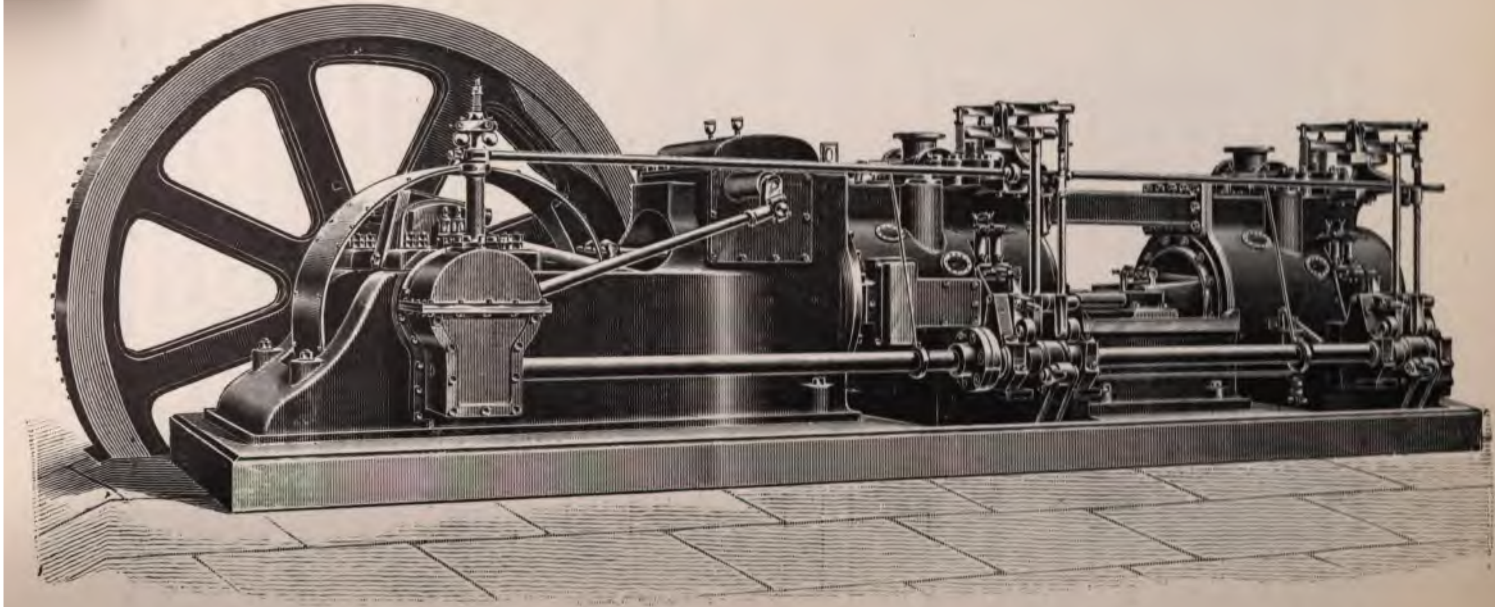


FIG. 152.—PREMIER TANDEM GAS ENGINE, 500 HORSE-POWER WITH MOND GAS, 1900.

by water circulating inside them. The valve is worked by lever with double bearings on brackets supporting the cam shaft. Each cylinder is provided with two porcelain ignition tubes placed side by side with timing valves. If one tube bursts the other can be immediately put into action, without stopping the engine, by changing over a tumbler which works the timing valve of the spare tube. Electric ignition is also employed. The first 500 horse-power engine at Sandiacre was supplied with clean gas from the Mond plant, without ammonia recovery; part of the exhaust gases from the engine being added to the air and steam blast of the gas producer, in order to increase the carbonic acid gas to be reduced therein to carbonic oxide. The Mond gas produced in this way from Nottinghamshire free burning small coal has an effective calorific value of 142 to 150 B.Th.U. per cubic foot at 60° F. and atmospheric pressure. About one-third of the net heat is converted into work done on the piston. Figs. 153 and 154 show indicator diagrams taken from the motor cylinders during preliminary trial runs. The mean effective pressure on the piston is 109 lb. per square inch, and deducting 2 lb.

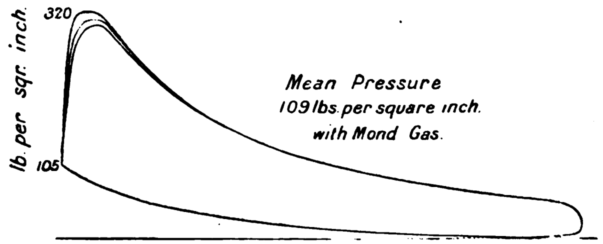


FIG. 153.—INDICATOR DIAGRAM. 500 HORSE-POWER PREMIER TANDEM ENGINE.

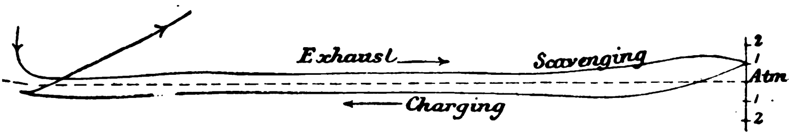


FIG. 154.—LIGHT SPRING DIAGRAM. 500 HORSE-POWER PREMIER TANDEM ENGINE.

per square inch for work done by the air pump, leaves the nett available pressure 107 lb. per square inch. At 128 explosions per minute the engine gives the maximum of 650 indicated horse-power with Mond gas. At the ordinary working load, 560 indicated horse-power, the mean effective pressure is 107 lb. per square inch, and the average consumption of Mond gas per indicated horse-power hour is 50 cubic feet, which gives 50 × 150 B.Th.U. The thermal efficiency of the engine is $\frac{2545}{50 \times 150} \times 100 = 33{\cdot}9$ per cent.

Under normal working conditions the 1000 horse-power Mond plant at Sandiacre makes 63 cubic feet of this quality gas from every pound of slack or small coal of the Midlands, fed into the producer, including that used in the boiler for steam. The calorific value of the coal, measured in the bomb calorimeter, is 12,200 B.Th.U. per lb., so that the thermal efficiency of the Mond gas plant, without ammonia recovery, is equal to $\frac{63 \times 150}{12{,}200} \times 100 = 77{\cdot}5$ per cent. The combined thermal efficiency of the gas plant and Premier gas engine is, therefore, equal to $77{\cdot}5$ per cent. $\times$ $33{\cdot}9$ per cent. $=$ 26 per cent. In other words, this gas-power plant converts into indicated work one-fourth of the heat of combustion of Midland slack. Also one pound of slack coal consumed per hour gives one brake horse-power. This makes the mechanical efficiency of this tandem Premier engine under favourable conditions $\frac{50}{63} \times 100$, or about 80 per cent. for everyday working. By regulation of the temperature in the large masses of metal with cooling water, and by thorough scavenging with air, the engine can work continuously at its rated power with regular ignition. The total lubricating oil for the engine amounts to four gallons in twenty-four hours, at a cost of 3*d.* per hour. When driving a dynamo the electrical output is about 70 per cent. of the indicated horse-power.

In addition to the work lost in engine friction, the loss by fluid resistance in the pumping strokes, Fig. 154, and air pump, Fig. 150, is 36 horse-power, equal to $5{\cdot}5$ per cent. of the full indicated power. The friction and wear are reduced by having the large cross-head end of the front piston working in the cool cylinder, next the crank-shaft, with very large bearing surface kept flooded with oil on its lower side. The gudgeon-pin bearings on each side of the connecting rod, Fig. 148, have twice the usual surface, are easily got at for adjustment, and can be kept cool and lubricated efficiently. To prevent knocking at the joints, the pressure of the charge during compression acts like an air buffer, and is made high enough to bring the moving parts to rest by overcoming their inertia forces. For tests of this engine see pages 585 and 625.

A similar engine of 1000 horse-power is designed by Mr. J. H. Hamilton, B.Sc., who has calculated the **variation of speed in each revolution** of these tandem scavenging engines.

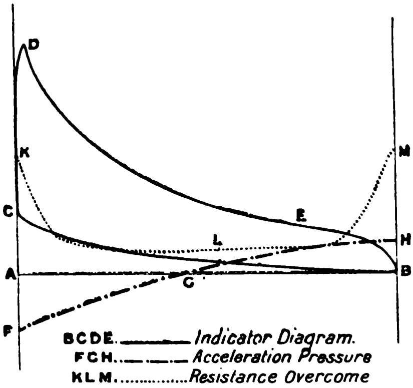


FIG. 155.—PRESSURE CURVES. PREMIER TANDEM ENGINE.

The compression curve B C and the expansion curve D E B of the *indicator diagram*, Fig. 155, shows the pressure of the gas on the piston at every part of the return and forward strokes, the pressure on the other side of the piston being atmospheric.

The *acceleration pressure curve* F G H gives the pressures required to overcome the inertia of the reciprocating parts of the engine, including the pistons, piston rods, cross-head and connecting rod, to increase their velocity during the first part of the stroke, and which is given back to the crank pin during the last half of the stroke while the reciprocating parts are being brought to rest. The area F G A representing the energy absorbed by the reciprocating parts is practically equal to area G B H, the energy restored by them to the crank pin. It is clear that the inertia of the reciprocating parts tends to equalise the pressure on the crank pin. Further, the compression during the return stroke is almost always in excess of the inertia pressure in this tandem engine, so that there is no reversal of pressure, and the brasses can run slack without knocking.

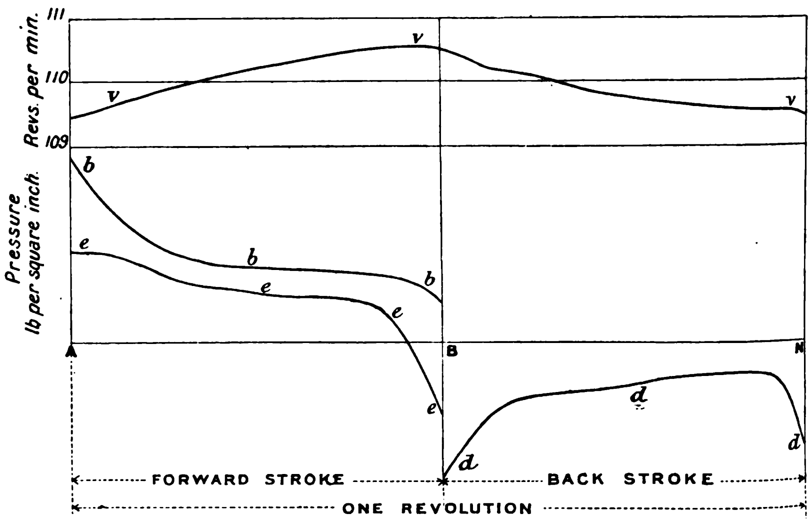


Fig. 156.—Fluctuation of Energy and Speed Curves.

To **allow for the effect of inertia** of the reciprocating parts on the pressures, set out on the base line A B, Fig. 156, the difference between the curves, Fig. 155. That is, from the pressures on the indicator diagram curve D E B subtract the pressures along F G spent in accelerating the reciprocating parts, and add the pressures along G H restored to the crank pin. We get the curve *b b b*, Fig. 156, and the ordinates from it to the base line represent the actual pressure transmitted to the crank pin at every point of the explosion stroke. Thus, to a known scale, the area A *b b b* B represents the work done during the explosion stroke, after allowing for the inertia of the reciprocating parts.

Again, the pressure curve K L M, Fig. 155, shows the work done during each stroke in overcoming the friction of the engine and driving the dynamo with constant load. The difference between the curves of effective driving pressure and resistance gives the curve *e e e*; and the area bounded by *e e e* and the base line represents the excess energy or work absorbed by the fly-wheel during the forward or explosion stroke, when the turning effort is in excess of the resistance.

In the same way the area *d d d* N B shows the work given out by the fly-wheel to the crank-shaft during the return stroke, to compress the next charge in the cylinder, overcome frictional resistance, and drive the dynamo.

The **fluctuation of energy** and the constant rate of doing work during one complete revolution being found, a suitable fly-wheel is designed to reduce the variation in speed of the engine as shown by the curve *v v v*, Fig. 156, when there is an explosion and a compression stroke every revolution.

The lowest speed is at the end of the compression stroke before ignition of the charge, and the highest speed is reached towards the end of the explosion stroke.

When the Premier tandem engine, coupled to a dynamo, and with suitable fly-wheel, is running light with one explosion every five revolutions of the crank-shaft, the variation of speed is from 110 at the end of compression of the charge to 111·5 revolutions per minute at the end of the explosion stroke. The speed afterwards fluctuates slightly, due to the inertia of the moving parts, and falls gradually to 110 revolutions per minute. It is interesting to compare and contrast, Fig. 156, with the velocity variation curves from direct measurement in the case of a single cylinder engine, given above in Chapter I.

—On May 23 and 24, 1898, a Premier tandem
cylinder 17 inches in diameter and 24 inches
in Glasgow with Dowson gas from Scotch
a run of 24 hours indicated 3528 horse-
average of 147 indicated horse-power.

The total coal used in the generator was 3017 lb., including waste in clinkering three times. After deducting the 350 lb. of cinder and ashes so taken out, the combustible used in the generator per indicated horse-power was 2667 / 3528 = 0·75 lb. The total coal was 3017 / 3528 = 0·85 lb. per indicated horse-power hour. The indicator diagrams, Fig. 157, are fair samples of those taken from the two cylinders during the trial. The back pressure was caused by the exhaust silencer. Next day, during 7 hours 10 minutes, the engine indicated 1636 horse-power hours, and the total coal used in the generator amounted to 1326 lb., that is, 0·81 lb. per indicated horse-power per hour.

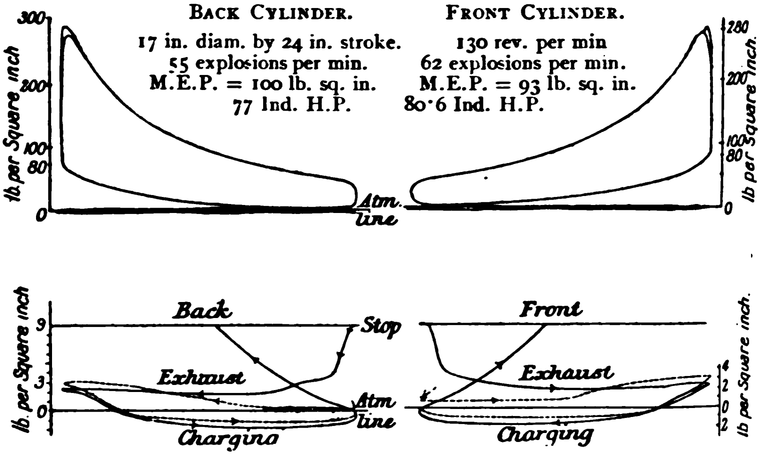
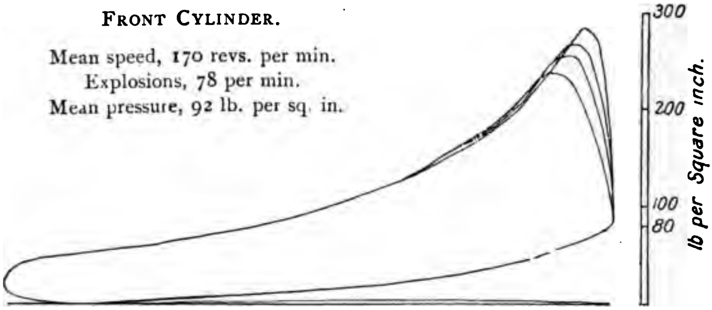


FIG. 157.—INDICATOR DIAGRAMS. PREMIER TANDEM ENGINE USING DOWSON GAS.

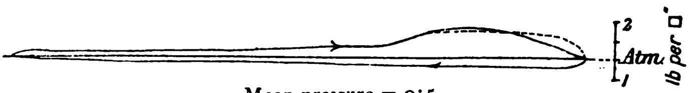
On October 5 and 6, 1897, the Author, assisted by Messrs. W. H. Everett, B.A., and J. Duncan, tested a unique plant at the works of the Star Brush Company, Holloway, London, N. A Dowson gas producer supplies a 100 horse-power Premier tandem scavenger gas engine, driving a three-phase alternator, designed by Mr. E. F. Bradley. The field magnets are built on the main crank-shaft, and serve as fly-wheel for the gas engine. The three-phase current is supplied to asynchronous electric motors in the factory, the rotating part of each being mounted on the shaft of its machine. For the purposes of the test, a triple resistance of salt water in barrels gave an adjustable, steady and balanced load. A Thomson-Houston integrating watt meter measured the electrical output, and was subsequently calibrated over the same range of load.

The cylinders of the engine are 15 inches diameter, the stroke 21 inches, and the air pump 25 inches diameter. In a preliminary run of 2 hours it was found that the producer was only able to make gas enough to supply the engine at **half load.** During the trial of 6 hours, the engine ran at 170 revolutions per minute, and the average effective indicated power, 58·6 horse-power, was mainly developed in the front cylinder, with an average of only two explosions per minute in the back cylinder. Indicator diagrams, Figs. 158 and 159, taken regularly every fifteen minutes from the motor cylinders and air pump, give the pressures therein, whilst the half-minute diagram, Fig. 160, shows how the explosions vary. Complete indicator diagrams for half minutes were also traced on one card, and the average power calculated therefrom, as nearly as possible without a continuous integrating indicator (see page 368). The total electrical output for the 6 hours was 216 horse-power hours, or an average of 36 horse-power. The anthracite coal used in the generator, without any allowance for


FRONT CYLINDER.

Mean speed, 170 revs. per min.
Explosions, 78 per min.
Mean pressure, 92 lb. per sq. in.

FIG. 158.—INDICATOR DIAGRAM. 100 HORSE-POWER PREMIER ENGINE.



Mean pressure = 0·5.

FIG. 159.—INDICATOR DIAGRAM. AIR PUMP.

that combustible lost in clinkering, amounted to 476 lb., or 79·3 lb. per hour; that is, at the rate of 1·35 lb. per indicated horse-power hour, and 2·2 lb. per electrical horse-power hour. The heating value of samples of the coal used, as found by the Berthelot bomb calorimeter (page 446), was 14,400 B.Th.U. per lb.; and that of the Dowson gas, tested in the Junkers calorimeter several times during the trial, was 147·6 B.Th.U. per cubic foot, and deducting 6·6 B.Th.U., the latent heat of steam formed by the combustion, gave the average effective value of the gas 141 B.Th.U. per cubic foot. The heating value of good Dowson gas from anthracite is at least 156 B.Th.U. per cubic foot. This gas was inferior in quality, and varied in calorific value between 166 and 137 B.Th.U. per cubic foot. Under these unfavourable conditions **at half load**, the gas engine and alternator gave very satisfactory results. When the producer was not supplying the gas-holder, the engine used the Dowson gas therefrom at the rate of 4350 cubic feet per hour, and developed 58·6 indicated horse-power. This gas consumption was 74·2 cubic feet per indicated horse-power hour. The effective heating value of the gas being 141 B.Th.U. per cubic foot, we find the heat supplied to the engine 141 × 74·2 = 10,462 B.Th.U. per hour for every horse-power generated in the cylinder. Now the heat equivalent to a horse-power hour is 2545 B.Th.U., therefore the engine turned into work is 24·3 per cent. of the available heat supplied in the gas, a good thermal efficiency at half load.

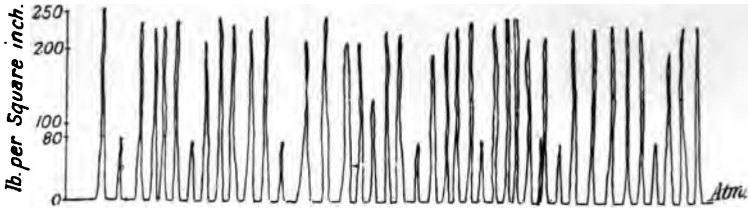


FIG. 160.—EXPLOSIONS IN FRONT CYLINDER DURING ½ MINUTE.
34 explosions and 8 misses.

In October 1897, Professor Henry Robinson made tests of Premier gas engines (Otto cycle type, Fig. 138), Dowson gas generators and electrical plant at the Leyton Central Lighting Station, under ordinary conditions of working, with the following results :—

	October 26. 2 Engines at Full Load and 1 Producer.	October 27. 4 Engines, and 2 Producers at ⅔ Full Load.
Duration of test, in hours	5	5
Average consumption of coal per hour, lb. .	98·5	151·2
" " coke " " .	14·4	17·2
Total output, electrical supply units. . .	319	402
Average indicated H.P. of engine No. 4 . .	59·5	43·5
" electrical H.P. of dynamo No. 4 .	43·7	29·2
Total indicated H.P.	116·4	160·4
" electrical H.P.	85·5	107·6
Coal consumption per indicated H.P. per hour, in lb.	0·846	0·942
Coal consumption per brake H.P. per hour in lb.	0·975	1·128
Coal consumption per electrical H.P. per hour in lb.	1·152	1·405
Total fuel (coal and coke) per electrical unit in lb.	1·768	2·094
Gas consumption per indicated H.P. per hour .	..	80 cubic feet
Heat value of the gas in British thermal units per cubic foot at 60° F.	153	156

The coal used was anthracite supplied for ordinary working at 20*s.* 6*d.* per ton delivered at the works. In the second test the four machines were put in parallel at two-thirds of full load, and the dynamos ran with fairly equal distribution of load and with practically no sparking. The records of the cost of fuel, from January till October, show that it was only 2/3rds of a penny per Board of Trade electrical unit sold. During the winter months, with larger load factor, the cost per kilowatt-hour is even less. For September the coal and coke amounted to 2·35 lb. per kilowatt-hour generated, and cost one farthing.

Professor John Goodman tested two Premier gas engines driving dynamos for electric lighting at the Yorkshire College, Leeds, in the year 1896.

RESULTS OF TRIAL. PREMIER ENGINE, WITH LEEDS COAL GAS.*

	Full Power.	Half Power.
Duration of trial . . . . . hours	2	2
Mean revolutions per minute . . . revs.	152·8	156·8
Mean indicated H.P. . . . I.H.P.	61·5	39·5
,, electric ,, ... E.H.P.	47·5	23·2
Electric H.P. ÷ indicated H.P. . per cent.	77·2	58·7
Gas used, including ignition, at 32° F. and 14·7 lb. per square inch . . per I.H.P. hour, cub. ft.	15·27	20·9
per E.H.P. hour, ,,	19·77	35·6
Ratio of air to gas by volume	12·7 to 1	14·3 to 1
Heating value of gas at 32° F. and 14·7 lb. per square inch, in British thermal units per cubic foot . . . . . . B.Th.U.	652	652

Taking the price of gas in Leeds, 2*s.* per thousand cubic feet, the cost at full load was about ½*d.* (0·48*d.*) per electrical horse-power per hour; and the total cost of lighting was 1*d.* per kilowatt-hour, exclusive of wages.

The **National Gas Engine** (Bickerton & Bradley patents), built by the National Gas Engine Company at Ashton-under-Lyne, is an excellent example of a modern single-cylinder horizontal gas engine working on the four-stroke or Otto cycle. The general view, Fig. 161, the longitudinal section of cylinder, with valve arrangement, Fig. 162, also the sectional end elevation through charging valve, Fig. 163, give a good idea of the design of the different sizes up to 50 effective horse-power.

The crank shaft is of great strength, with suitable bearings for two heavy fly-wheels. In the combustion chamber C, Fig. 162, the cooling surface is reduced by doing away with port passages, except from the charging valve V. The valves are of the conical-seated lift type, having easy access for cleaning by removable covers J J with ground joints. The seating and spindle guide of the exhaust valve R are part of the main casting, in order to avoid the trouble of broken joints. The gas and air admission valves, G and V, are in a separate casting bolted to the back end of the cylinder. A special feature of this engine is the porcelain ignition tube fixed on the *side* of the cylinder at the piston end of the compression space. The porcelain tube, open at both ends, is supported on asbestos washers to prevent contact with the cold metal, whilst the iron tube extension above the porcelain can be kept tight by the screw at the top. The side ignition works well in practice ; and the clay tube, which costs 6*d.*, lasts about twelve months. All engines above 8 brake horse-power have timing valves T, Fig. 163, operated by the lever Q from a cam on the side shaft S.

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* See *Proceedings Inst. Mech. Engineers*, July 1896.

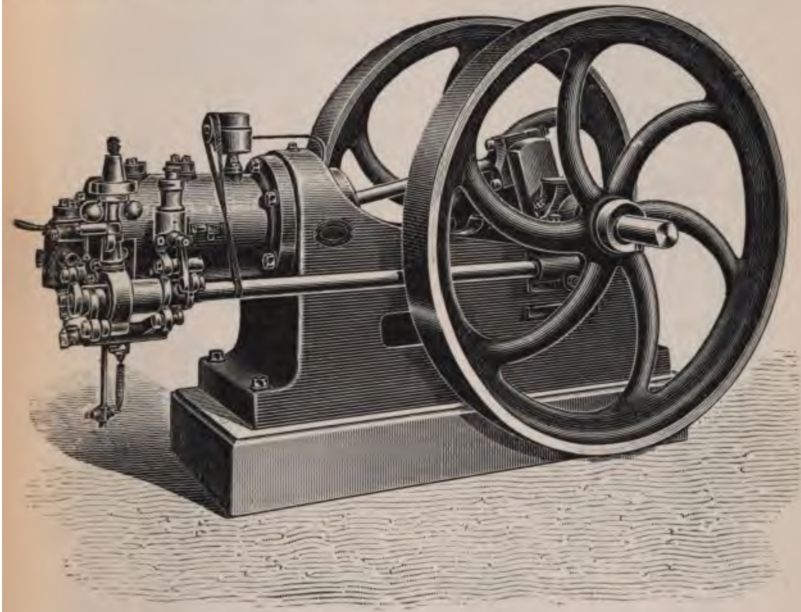


FIG. 161.—THE NATIONAL GAS ENGINE.

The *centrifugal governor* F has a steady drive from the side shaft by skew gear, and is loaded by a dead weight and spring. The governor *control* on the gas valve G is direct and simple, allowing full charge of gas or none at all. The pecker M pushes the gas valve spindle through the notched piece N as the cam X on the side shaft raises the roller of the lever which turns about H. When the speed exceeds the normal, the governor lifts the piece N by means of the lever Y, so that the pecker M fails to move the spindle, and the gas valve G remains closed.

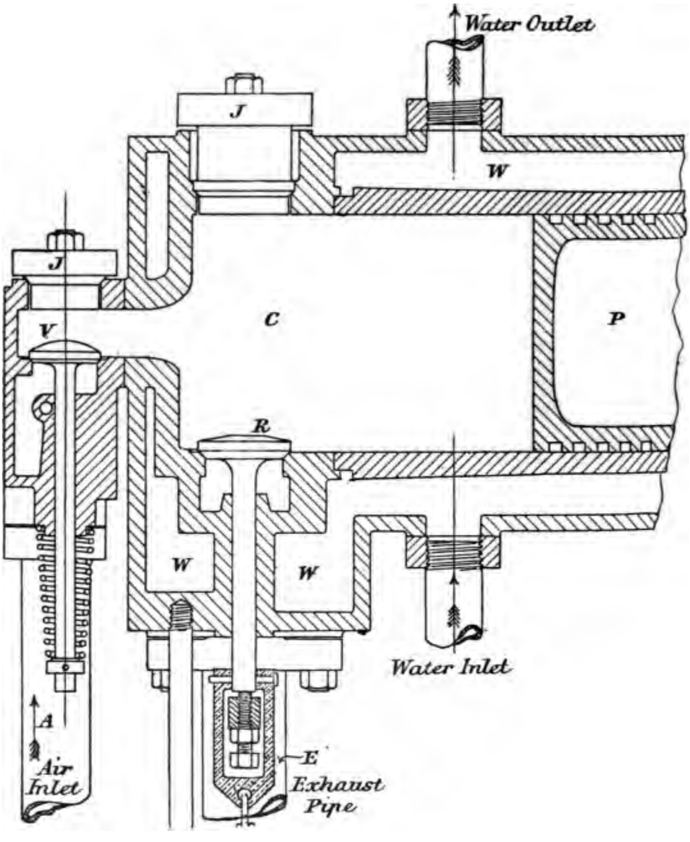


Fig. 162.—National Gas Engine (Section of Cylinder.)

The usual compression of the charge before ignition is from 85 to 95 or even 100 lb. per square inch. The engine is well built, and runs quietly with great regularity of speed.

Trial.—On October 7th, 1898, the Author made a full-power brake test of a National gas engine, 10 horse-power nominal, the cylinder 10 inches in diameter and 18 inches stroke. The volume swept by the piston was 1413·7 cubic inches, and ıe compression space, measured by water, 339 cubic inches. 'hese volumes are in the ratio of 1 to 0·24. The expansion ıtio, that is, of the compression space to the total volume t the end of the working stroke and charging stroke, was 39 / 1753 = 1 ÷ 5·17. This gave high compression of the

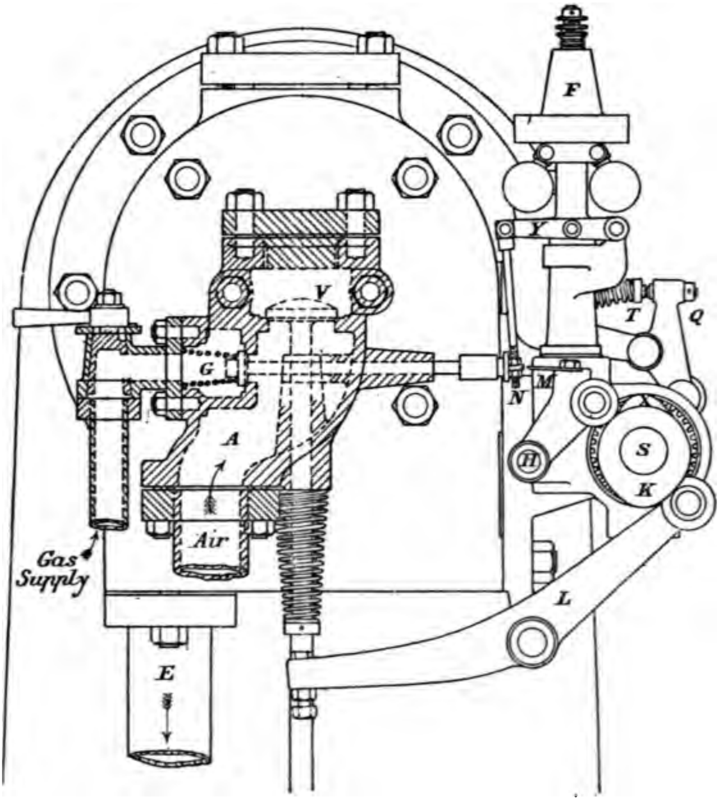


FIG. 163.—NATIONAL GAS ENGINE (SECTIONAL END ELEVATION).

harge before ignition, 110 lb. per square inch, which was sed in order to have results comparable with those from other ngines under similar conditions. Other things being equal in well designed engine, the gas consumption is less as the compression is raised. The usual compression for everyday work 95 lb. per square inch. The engine was running with full load for about two hours before test. The brake consisted of a rope wound on a drum kept cool by water inside the rim. The weight was hung on the rope, and a spring balance took the pull at the other end. The weights and instruments used were tested and calibrated. Messrs. W. H. Everett, B.A., B.E., and H. R. Cullen, B.A., assisted the Author in taking observations; simultaneous readings were taken every 5 minutes.

RESULTS OF TRIAL, NATIONAL GAS ENGINE, October 7, 1898.

Duration of full load trial run		1 hour
Revolutions per minute (mean) . . .		170·3
Explosions ,, ,, ...		82·5
Pressure before ignition (above atmospheric), lb. per square inch		110
Explosion pressure, lb. per square inch . , .		350
Mean effective pressure, ,, ,,	90·6	
Mean back pressure, pumping strokes	1·0	89·6
Indicated horse-power		26·4
Brake horse-power		23
Mechanical efficiency		87 per cent.
Gas used per hour (main), cubic feet. . . .		369·2
,, ,, (ignition burner), cubic feet . .		2·3
Total		371·5
Gas per effective indicated H.P. hour, (total) cubic feet		14·03
,, brake H.P. hour, (total) cubic feet . .		16·15
Heating value of gas, effective B.Th.U., per cubic foot		630
Cooling water through jacket, lb. per minute . .		8·15
Rise in temperature of water, 54·5° to 212° F. . .		157°·5
Thermal efficiency:—		
Heat turned into nett work indicated in cylinder .		28·7 per cent.
,, ,, on the brake . .		25·0 ,,
Heat lost by jacket water		32·9 ,,

The mean piston speed was 170·3 × 3 feet = 511 feet per minute. The greatest variation in the mean speed, for every five minutes, was from 169·6 to 171 revolutions per minute, that is, only 0·4 per cent. from the mean. The running was remarkably smooth, quiet and regular. The gas consumption was remarkably low—in fact, one of the best results on record at that date.

The heating value of the Ashton coal gas, as used by the engine, was determined by Junkers calorimeter during the run, and checked by observations during fifteen minutes before and after the trial. It was found to be 696 B.Th.U. per cubic foot at 65° F. and 15 lb. per square inch. Deducting 65 B.Th.U., the latent heat of the steam formed in burning a cubic foot of the gas, the effective heating value of the gas was 630 B.Th.U. per cubic foot actually used in the gas engine cylinder. We have the **distribution of heat** in the engine during the trial as follows:—

RESULTS OF TRIAL, NATIONAL GAS ENGINE, October 7, 1898.

Heat Distribution.	B.Th.U. per Min.	Per Cent.
Total heat supplied to the engine: —		
6·19 cubic feet × 630 B.Th.U. . .	3900	100
Heat utilised as nett work done:—		
Indicated H.P., 26·4 × 42·4 . .	1119	28·7
Brake H.P. 23 × 42·4 . .	975	25
Heat carried away by cooling water in jacket:—		
8·15 lb. × 157°·5 Fahr.	1284	33
Heat lost by exhaust, and unaccounted for .	1497	38·3

The cost of coal gas at Ashton-under-Lyne is 2*s.* per 1000 cubic feet, so that the cost of fuel per brake or effective horse-power during this trial run was 0·39*d.*

The indicator diagrams, Figs. 164 and 165, are fair specimens of those taken during the trial. The spring used was tested in the indicator by comparison with a mercury column and steam pressure. The engine was not working at the maximum load, as the governor cut off a charge every two or three minutes. Still the load was large enough for continuous working, and none of the bearings were more than milk warm. The results are excellent, the thermal efficiency of the engine being 28·7 per cent., and the variation in speed very small.

Tangyes Gas Engine.—Since 1891, Messrs. TANGYES LIMITED, Birmingham, have built four-stroke cycle gas engines with the improvements patented by Mr. C. W. Pinkney. All sizes are of the single-cylinder horizontal type, from the "Baby" of 1 brake horse-power to the large engine having a cylinder 24 inches diameter by 30 inches stroke, giving, at 150 revolutions per minute, 125 brake horse-power with producer gas. The usual practice is to allow 80 per cent. of the maximum power with cheap fuel gas for the continuous working load. Under favourable conditions the 125 horse-power engine developed a maximum of 140 brake horse-power with producer gas from Scotch anthracite, and its ordinary working load is 100 brake horse-power.

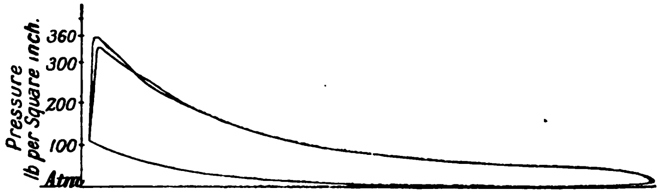


FIG. 164.—INDICATOR DIAGRAM. NATIONAL GAS ENGINE.

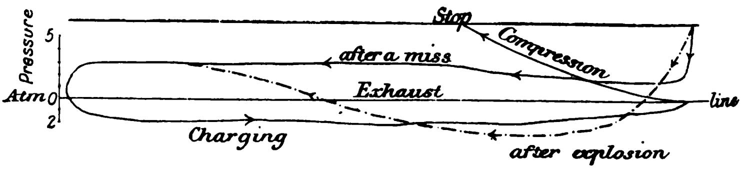


FIG. 165.—NATIONAL GAS ENGINE. LIGHT SPRING DIAGRAM (PUMPING STROKES).

Fig. 166 is a general view of the engines from 40 to 100 brake horse-power. The cylinder, fitted with a liner of special hard metal, is bolted to the engine bed which rests on the foundation, and comes well under the cylinder to support it. The combustion chamber is made conical in shape to prevent severe shock and have the charge burning during the whole of the explosion stroke. The air, gas and timing valves are placed at the end of the combustion chamber and in one

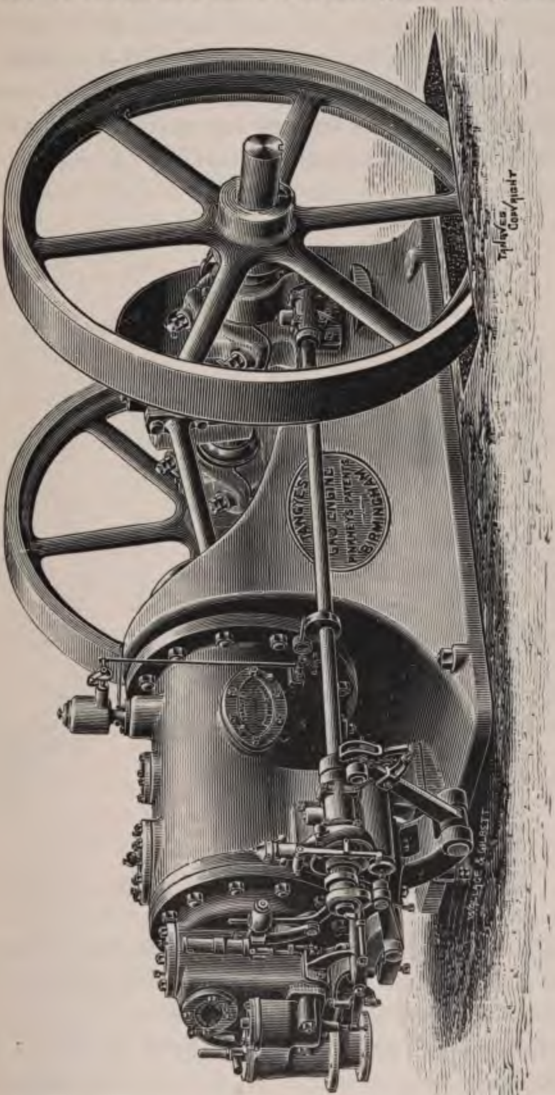


FIG. 166.—TANGYES SINGLE-CYLINDER GAS ENGINE.

casting with it, forming the back cover, bolted to the end of the cylinder. In any large engine the gas valve is necessarily very heavy, causing a great deal of wear on the knife edges of narrow cams and rollers employed to operate the gas valve. To overcome this difficulty, in their 125 horse-power engine Messrs. Tangyes employ an auxiliary gas valve lever and cam to operate a tumbler working in a guide bracket between the gas-valve spindle and the gas-valve lever proper. The latter works every time. The tumbler, however, is controlled by the governor so that, when the engine is cutting out charges of gas, the tumbler is held in such a position that the lever misses it. The action may be seen from Figs. 167 and 168: A is the gas valve, B the main gas valve lever worked by cam C on the side shaft S. The tumbler D, working in the guide bracket E, is operated by the rod F,

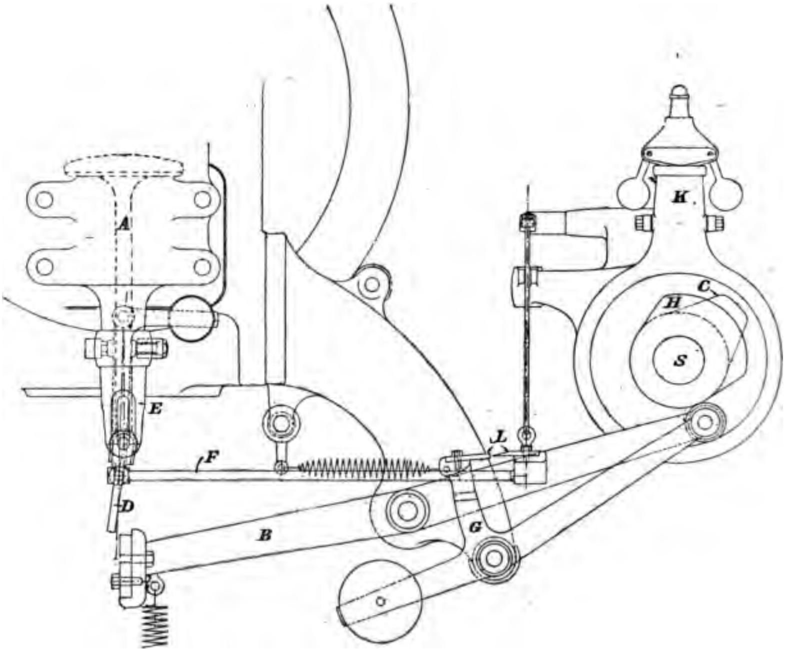


FIG. 167.—GOVERNOR GEAR. TANGYES GAS ENGINE.

lever G, and cam H. The centrifugal governor K controls the speed by raising and lowering the end of the rod F, causing the catch plates L to hit or miss as is necessary. These plates are made wide, and, having only to put the tumbler into position for lifting the gas valve, very little wear takes place. This engine has two exhaust valves—a small and a large one. The small valve opens in advance of the larger one and relieves the pressure, so that no great stress is

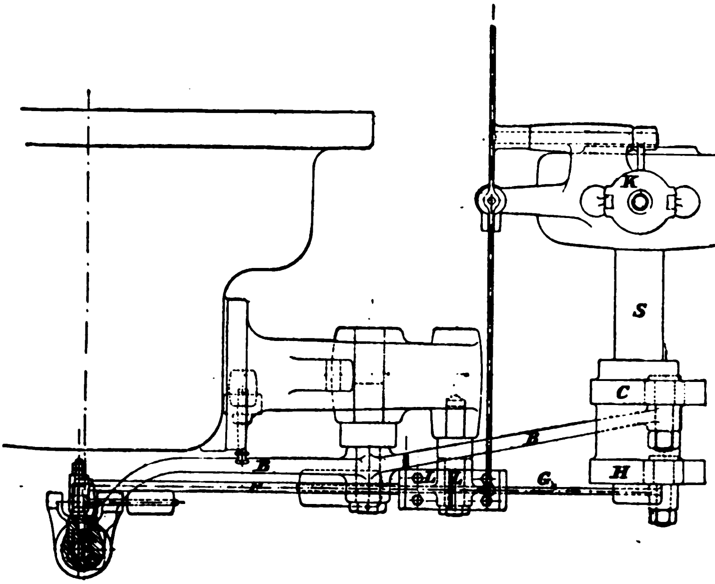


FIG. 168.—GOVERNOR GEAR. TANGYES GAS ENGINE.

rown on the mechanism for operating the valves. The lves are kept cool by water circulating through the interior them. When working with high compression in large gines, the combustion chamber is liable to become so hot at the incoming charge is fired before the end of the com-ession stroke. Then, again, stresses are produced in the etal by the high temperatures and unequal cooling of the ater-jacket, and the metal must be distributed so as to over-ome the uneven expansion.

The 1900 design of Tangyes, Fig. 169, for all sizes, is much simplified in construction for convenience of fitting and repairs. The compression of the charge before ignition is over 90 lb. per square inch in the larger engines. The exhaust valve box is in the same casting as the cylinder casing and combustion chamber. The exhaust valve lever is shortened. A little handle or lever is used instead of the pin for release cam. The cylinder liner has only two bearing surfaces with an asbestos joint next the combustion chamber, and a rubber with a ring of bolts fixing the liner to the cylinder cover at the crank end. The harder the engine works the tighter the joint becomes at the combustion chamber end. The porcelain ignition tube is without the iron extension, but has a space at its base around the nipple for the burnt products. The correct time for igniting the gaseous charge is determined by an adjustment of the chimney in the small engines, and by timing valve in the larger sizes.

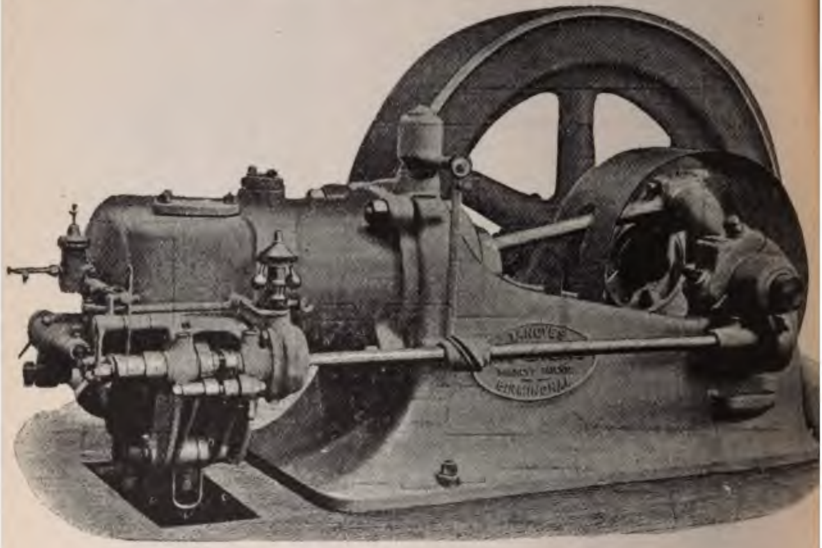


FIG. 169.—TANGYES GAS ENGINE, ELECTRIC LIGHTING TYPE, 1900.

For electric lighting, the variation in speed is kept low by putting on heavy fly-wheels and using a sensitive governor.

On an engine of 32 brake horse-power the one fly-wheel is 75 inches in diameter, and runs at 210 revolutions per minute.

In the small sizes of engines the speed is controlled by Pinkney's **incline or momentum governor.** The incline block C works on the roller R, and is operated by the cam K on side shaft, and the lever D swinging about the pin E, and provided with roller B, which is held against the cam by means of spiral springs. A broad knife-edged pecker P is moved in and out of line with a grooved catch-plate G on the gas-valve spindle.

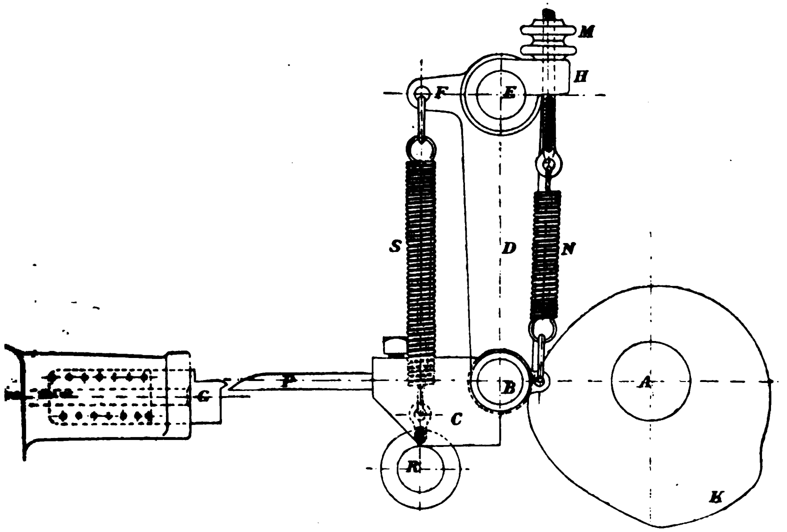


FIG. 170.—TANGYES INCLINE GOVERNOR, PINKNEY'S PATENT.

At the normal speed of engine the pecker P strikes the lever G near the point, and opens the gas valve. When the speed is too high the increased momentum of the incline block C causes the pecker P to be thrown up out of line with the catch-plate G, and the gas valve is not opened. The speed can be regulated whilst the engine is running by adjusting the spring N by the screw M to make the incline C press more or less tightly on the roller R.

A **pressure starter** is used with engines above 40 brake horse-power. A mixture of gas and air is pumped into a separate reservoir to about 80 lb. per square inch. With small engines a hand pump is used for charging the reservoir, but for large ones like the 125 horse-power engine, a small combined gas engine and pump is supplied. The compressed mixture in the reservoir is not explosive, being too rich in gas until mixed with the air in the cylinder. The crank is turned about 30° over the dead centre on the explosion stroke. The ignition timing valve E, Fig. 171, would in ordinary running be open at this point, but it is held closed on its seating by the lever K resting on the catch N on the cam I of side shaft S. The gas and air stored under pressure in the reservoir is now admitted to the cylinder through the valves A6, A4 and passage A7 to the combustion chamber B. The pressure moves the piston forward until the catch N releases the trip lever K, allowing the timing valve E to open, when part of the charge rushes up the ignition tube A8 and is fired, giving a strong impulse and driving the engine round until it takes gas and air in the ordinary way by the admission inlet valve G. As soon as the charge in the cylinder is fired, the valve A4 is shut down tightly. Fig. 173 shows a starting diagram and

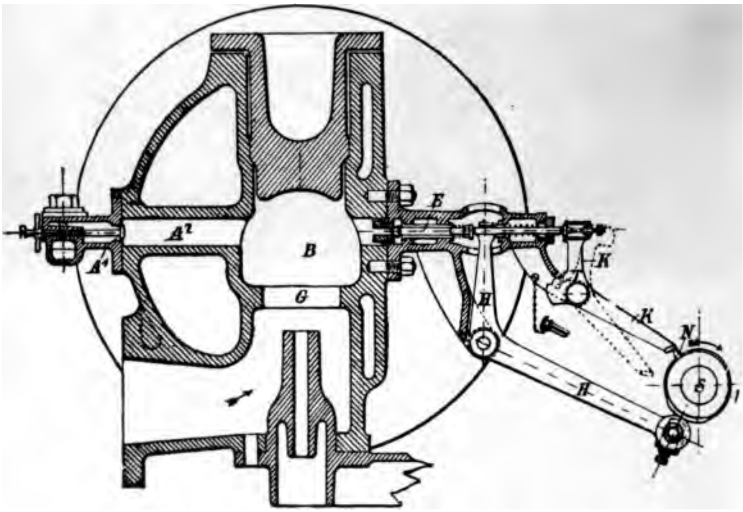


FIG. 171.—TANGYES GAS ENGINE (END ELEVATION OF IGNITION AND STARTING GEAR).

an ordinary one. The piston is at A1 when the compressed charge enters the cylinder, and is moved forward to A2 before firing. The working parts of the engine are in motion and the impulse is not felt as a shock. The dotted line, Fig. 173, is the ordinary indicator diagram.

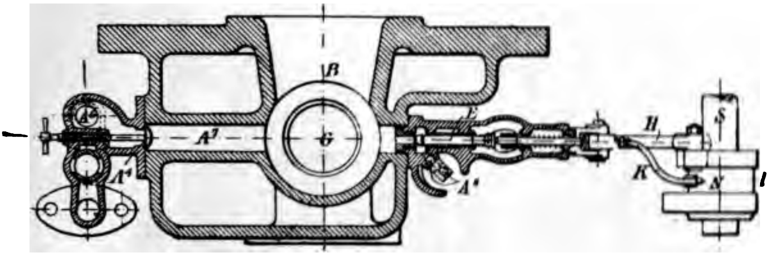


FIG. 172.—TANGYES GAS ENGINE (SECTIONAL PLAN OF IGNITION AND STARTING GEAR).

The consumption of gas, having a heat value of 650 British thermal units per cubic foot (or 5780 calories per cubic metre), is said to average from 16 cubic feet per brake horse-power hour in the larger to 20 cubic feet in the smaller

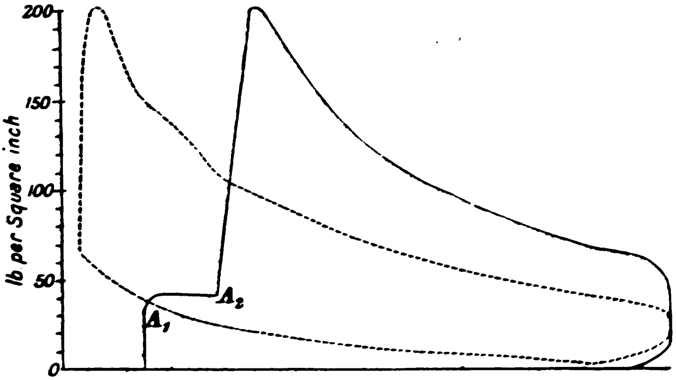


FIG. 173.—TANGYES STARTING AND INDICATOR DIAGRAM.

sizes under full test load at the Cornwall Works. In ordinary everyday work at lighter loads the consumption will be at a higher rate, although it is claimed that these engines run light on very little gas.

Forward Gas Engine.—Messrs. T. B. BARKER and COMPANY have adopted the Birmingham motto "Forward" for their simplified Otto gas engine. Fig. 175 is a longitudinal section, and Fig. 176 an end elevation of a 16 brake horse-power engine, and is a standard type for all sizes made from 3 to 53 brake horse-power, whilst the end view, Fig. 174, shows the valve gear and governor of the Forward Otto gas engine. The inlet valve G and the exhaust E are placed side by side and opening direct into the combustion chamber C. A spring H holds these valves on their seats by a stirrup or bridge piece. The charging valve G is opened by the

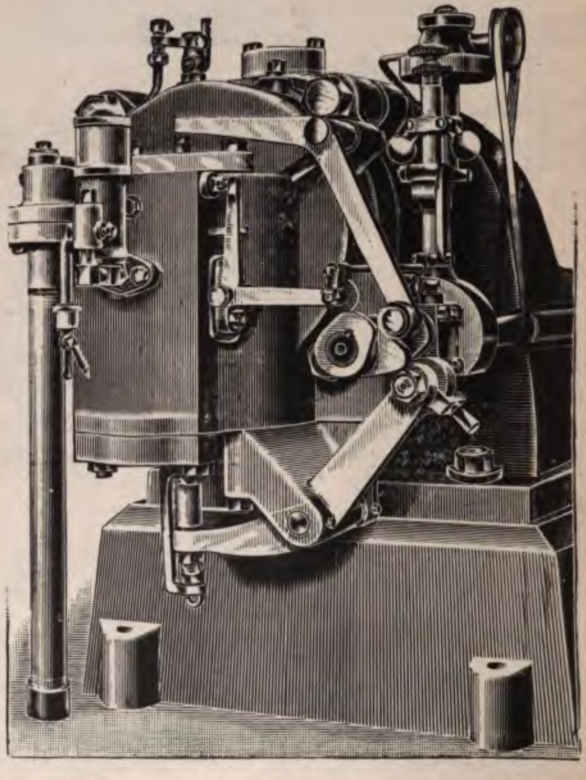
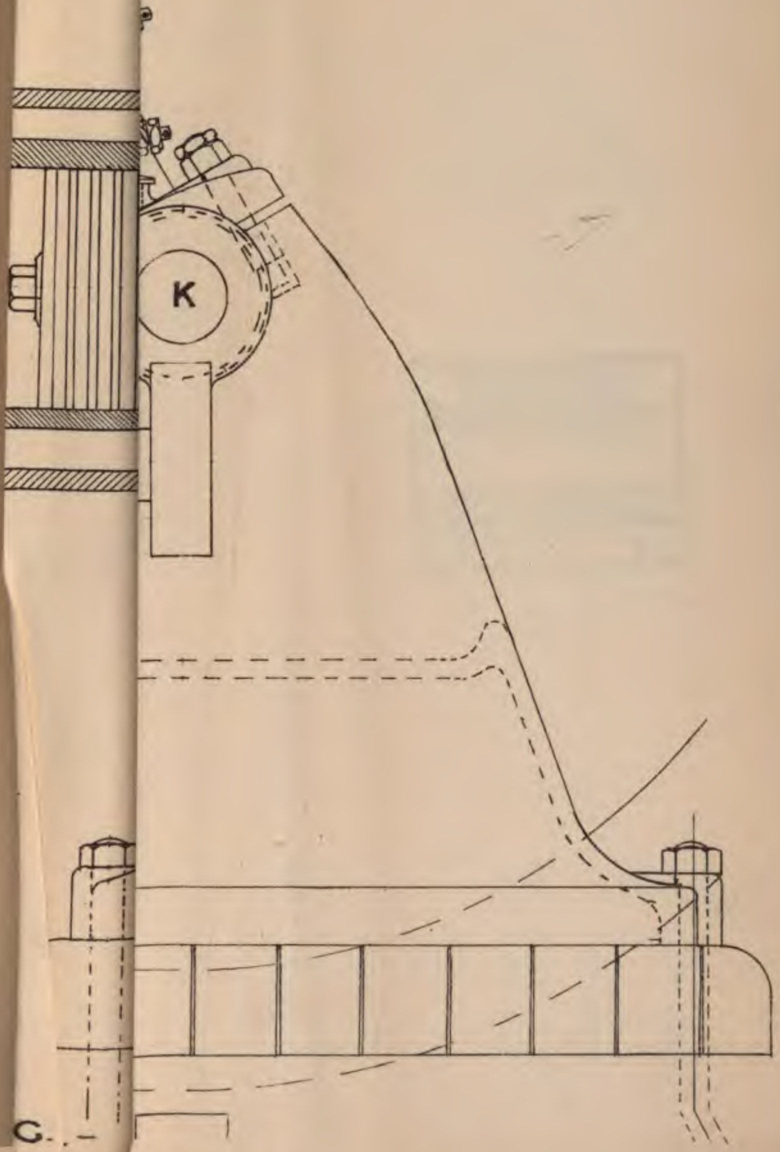


FIG. 174.—BARKER FORWARD GAS ENGINE (VALVE GEAR AND GOVERNOR).



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lever F, Fig. 176, actuated by cam on the side shaft S. The gas valve B is operated by the lever A with hit-and-miss mechanism controlled by the governor M, which is driven by bevel gear from the side shaft. Ignition is by heated tube I,

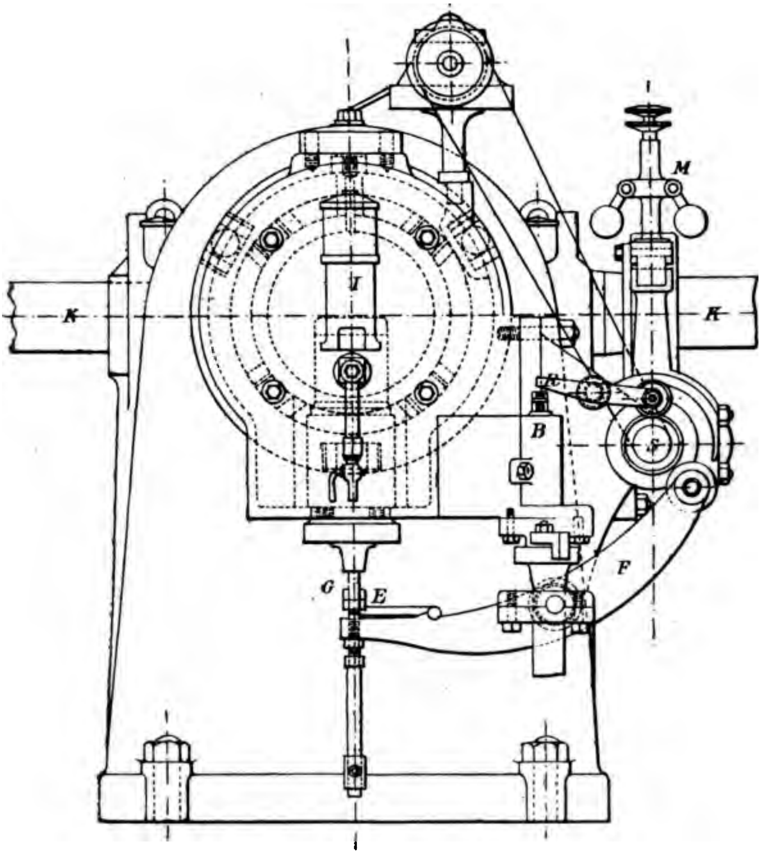

FIG. 176.—BARKER GAS ENGINE (END ELEVATION).

without a timing valve; and the time of ignition is adjusted by moving the Bunsen burner up or down.

This Forward engine is fitted with the **low-pressure starter** of Mr. F. W. Lanchester (patent No. 5479 of 1890), Fig. 177, which is also used on the Robey engine. A gas supply pipe with stop-cock S is fixed on the side of the cylinder A, whilst on the top is the ignition nozzle containing a check vaive V, cock C, and gas jet V. A special relief cam keeps the exhaust valve open during the whole compression stroke, allowing part of the charge to escape. The relief of the compression for starting was not new. In 1883 James Robson used it with the outside flame, which was sucked in through the ignition nozzle by the piston as the speed of the engine increased, and fired the cylinder gases at atmospheric pressure, like a non-compression engine, until it got up speed enough to run on the compression principle, when the flame was shut off and the ordinary firing used. In order to get the full impulse with the Lanchester starter, the method of working is as follows:—

The crank of the engine is set well over the in centre on the explosion stroke. The gas jet J is lit, and gas is introduced into the cylinder through the cock S. The gas mixes with the air in the cylinder, and part of the contents escape through the cock C and check valve V. The mixture is ignited by the jet J until it burns with a blue flame and peculiar roar,* indicating that the mixture is explosive. The inlet supply cock S is then shut off, causing the velocity of outflow through V to fall short of the velocity of propagation of the flame, which shoots back into the cylinder and ignites the contents at atmospheric pressure. The explosion pressure closes the check valve V and drives the piston. The indicator diagram, Fig. 178, was taken by the Author from a 36 brake horse-power Robey gas engine. The first low-pressure explosive curve is marked 1. After the exhaust stroke, the next charge of gas and air is drawn in by the piston in the ordinary way, but during the compression stroke the exhaust valve is held open by the special relief cam. Part of the charge escapes through the check valve V and is ignited by the jet J, and the flame is sucked into the cylinder, firing the charge as in an atmospheric gas engine.

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* In 1889 Hamilton and Rollason (patent 16,434) used a starting apparatus like this, in which the flaring up of the outside flame showed when the mixture became explosive.

The explosions 2, 3 and 4, Fig. 178, become later until the engine gets up speed enough to start against full compression, when the ordinary cam is used and the charge fired by the tube igniter. The Lanchester low-pressure starter is not sufficiently certain in its action, nor are the explosions

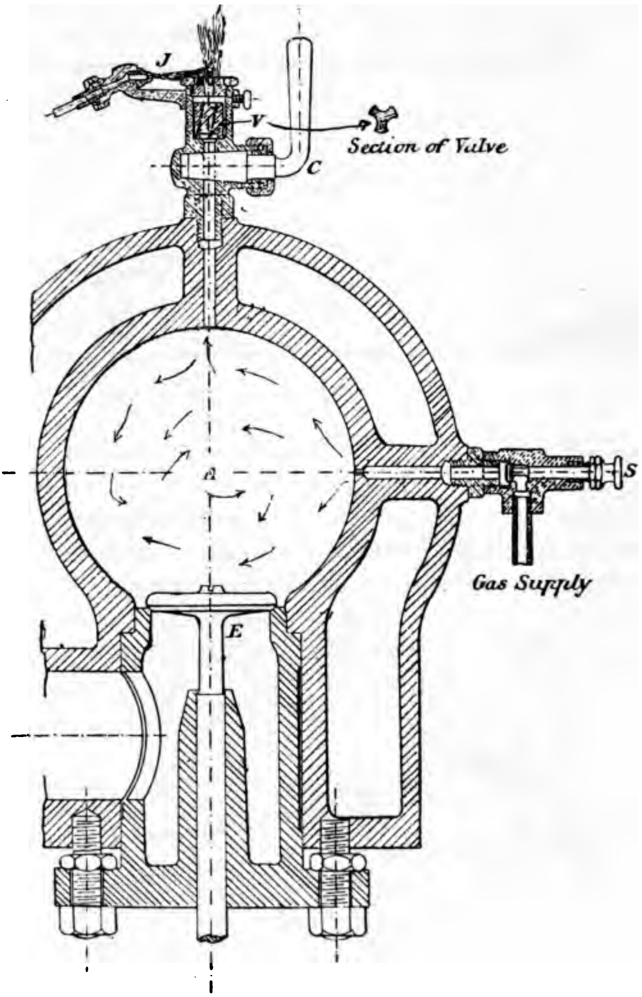

FIG. 177.—LANCHESTER LOW-PRESSURE STARTER.

obtained powerful enough to start an engine having any considerable frictional resistance and heavy fly-wheels.

Trials.—In 1894 a Forward engine, Fig. 175, built by Messrs. Barker, and designed, it is stated, by Mr. F. W. Lanchester, was tested* at the Birmingham Corporation Gas Works, Saltley, by Mr. J. W. Morrison, in conjunction with Mr. Lanchester. The engine cylinder was 12 inches diameter by 20 inches stroke, and gave 18·5 brake horse-power at 154·7 revolutions per minute, up to 29·8 brake horse-power at 207·25 revolutions per minute. The average consumption of gas (not including 6 cubic feet per hour for ignition) was 21·34 cubic feet per brake horse-power hour. The heating value of the Birmingham coal gas was calculated at 485,000 and 498,000 foot-lbs. per cubic foot.

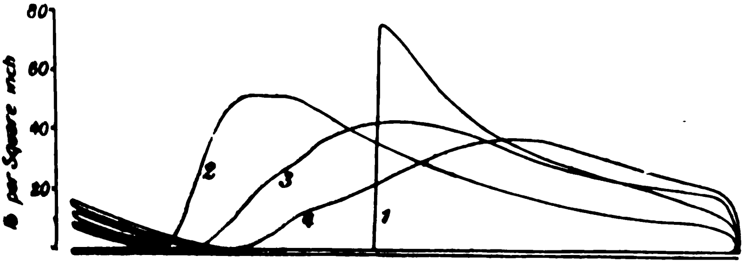

FIG. 178.—LANCHESTER STARTER DIAGRAMS.

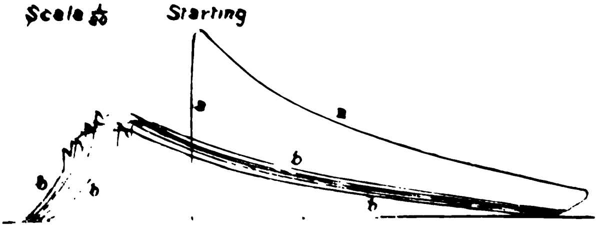

FIG. 179.

In Fig. 179 the diagram *a a* is from the first explosion, and *b b* the low-pressure explosions that follow. By Fig. 180

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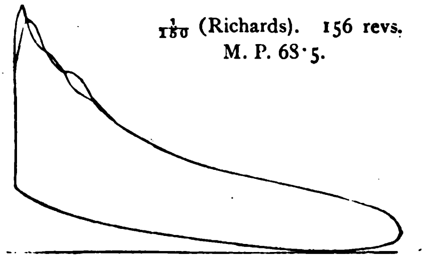
* For further details of the test, see *The Engineer*, April 6, 1894.

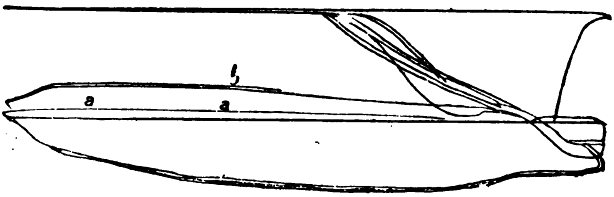
the pressure before ignition is 50 lb. per square inch, and the mean pressure 68·5 lb. The exhaust pressure, with the exhaust pipe entirely removed, is shown by curve *a*, in the light spring diagram, Fig. 181, at full load, and *b* is the curve obtained when running light. The mechanical efficiency varied from 76 to 84 per cent.



$\frac{1}{180}$ (Richards). 156 revs.
M. P. 68·5.

FIG. 180.—INDICATOR DIAGRAM. FORWARD GAS ENGINE.

Robey Gas Engine.—The horizontal single-acting Otto cycle gas engines made by Messrs. ROBEY and COMPANY, of Lincoln, (Richardson and Norris patents) are well designed and carefully constructed in sizes from ½ to 120 brake horse-power. Fig. 182 is a view of the 2½ to 8 brake horse-power engines, whilst the larger powers from 36 to 120 brake horse-power are of the girder type, Fig. 183. In the cylinder section, Fig. 184, the exhaust valve E opens directly into the combustion chamber C, which has a water-jacket with separate inlet and outlet pipes in the bridge pieces B. The



Scale $\frac{1}{12}$, charging diagram. 176 revs.

FIG. 181.—LIGHT SPRING DIAGRAMS. FORWARD ENGINE.

charge is admitted by the valve V, and the gas entering by the channel G meets the air coming by the bent pipe A from the silencing chamber with baffle-plates in the base of the smaller sizes, Fig. 182. The exhaust and charging valves can be removed by lifting the covers above them on the upper part of the cylinder. The combustion chamber, Fig. 183, is fitted with manholes for cleaning the jacket, and the covers are made thin to act as safety doors in case the jacket water is frozen. The large end of the connecting rod is fitted to the crank pin by a strap, gib and cotter. The crank is

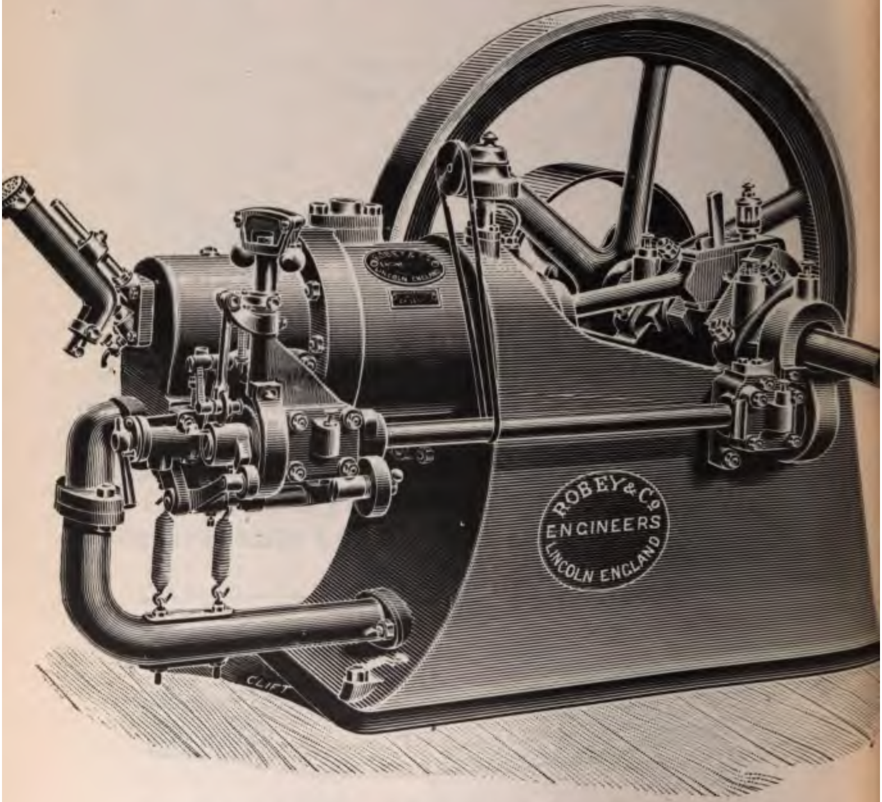


FIG. 182.—ROBEY OTTO ENGINE, 5 BRAKE HORSE-POWER.

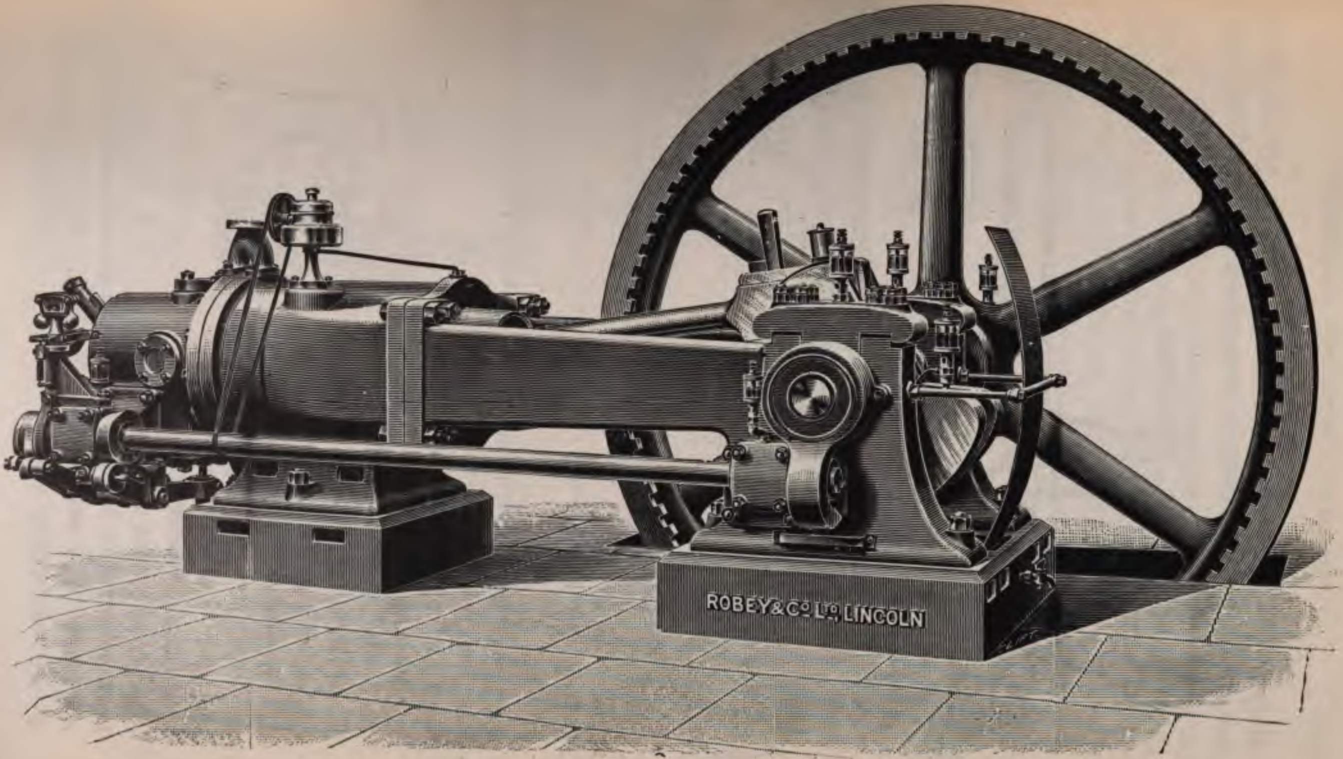


FIG. 183.—100 BRAKE HORSE-POWER ROBEY GAS ENGINE, GIRDER TYPE.

balanced on the webs. The main bearings are in four pieces, Fig. 185, adjusted horizontally by wedges and vertically by the cap and bolts. Ignition is by heated tube, controlled by timing valve in large engines, and by adjusting the position of the burner to suit the speed in the small engines. The engines can be made to run in either direction by altering the cams as marked thereon.

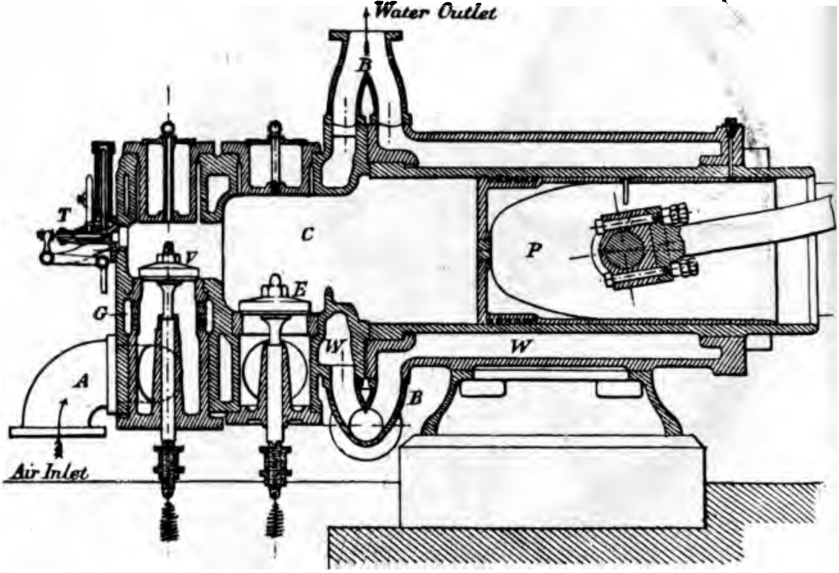


Fig. 184.—100 Brake Horse-power Robey Gas Engine, Girder Type.

Robey Governors.—In engines up to $1\frac{1}{2}$ effective horse-power the speed is regulated by a neat form of hit-and-miss inertia

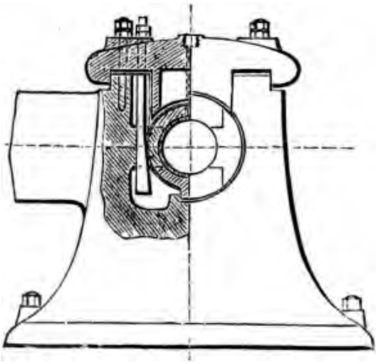


Fig. 185.—Robey Crank Shaft Bearing.

governor, Fig. 186. The pecker G, weight J, and spring H, are fitted on the air and gas valve lever C, which is actuated by the cam A on the side shaft S, opening the air valve D by the screw F, and the gas valve E by the pecker G. This pecker is held vertical by the spring H, but when the engine exceeds the normal speed, the inertia of the weight J overcomes the pressure of the spring and the pecker is drawn to

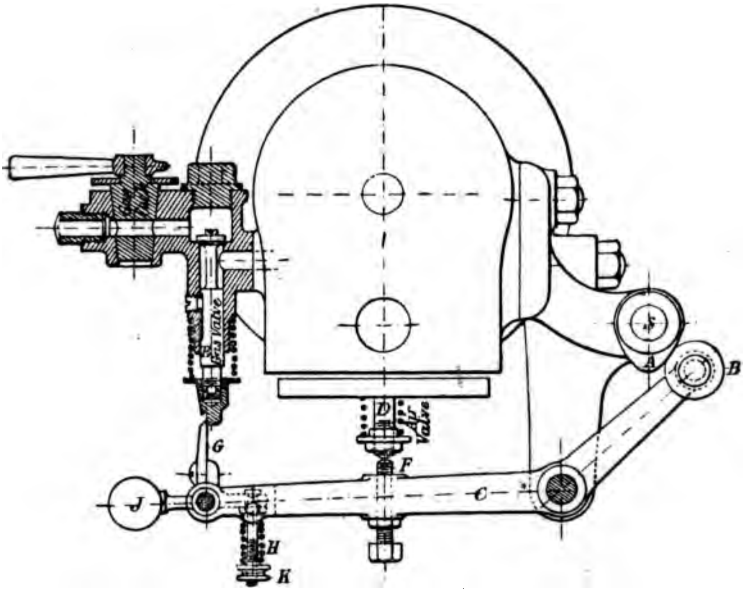


FIG. 186.—ROBEY INERTIA GOVERNOR.

one side of the gas valve spindle, so that no gas is admitted until the speed is reduced to the normal, when the spring pulls the pecker back again into action. The engine can be set to run at any desired speed by the regulating screw K.

The **Richardson centrifugal governor**, Fig. 187, is used on the large Robey engines. The lifting pecker F and gas valve spindle J are made of hardened tool steel, and have broad striking edges, notched and grooved, so that the wear is reduced to a minimum. Its action is easily understood from

Fig. 187. When the engine is at rest the governor balls are almost touching the sleeve on the spindle, and the crank lever D holds the pecker F under the gas valve spindle J, which is opened by the lever G driven by the cam H on the side shaft. When the speed rises slightly above the normal, the centrifugal force of the balls lifts the sleeve on the spindle and the end of lever D, so that the pecker F is pulled out of action away from the gas valve J and the gas is cut-out. The speed can be adjusted by the regulating screw K. The parts are proportioned so that a very small movement is sufficient to bring the pecker F out of action or to put it back again, the engine being compelled to run at a speed which maintains the governor in its mid-position.

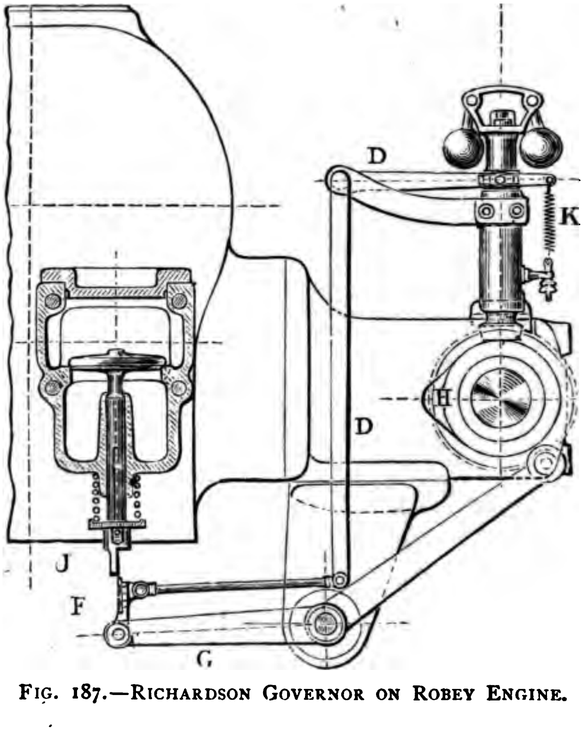


FIG. 187.—RICHARDSON GOVERNOR ON ROBEY ENGINE.

An **electric control**, Fig. 188, the invention of Mr. J. Richardson, M. Inst. C.E., may be used on gas engines driving dynamos for electric lighting. A pair of solenoids A, with laminated soft iron cores attached to a stud C, work the crank lever D, rod E and pecker F, which is actuated by the gas valve lever G and cam H, as shown in Fig. 188. For a constant potential at the terminals of the dynamo, high-resistance solenoid coils are used, connected as a shunt across the terminals of the machine. For a constant current, as in arc lighting, a low-resistance solenoid is joined in series with the main circuit. As the speed of the engine and current

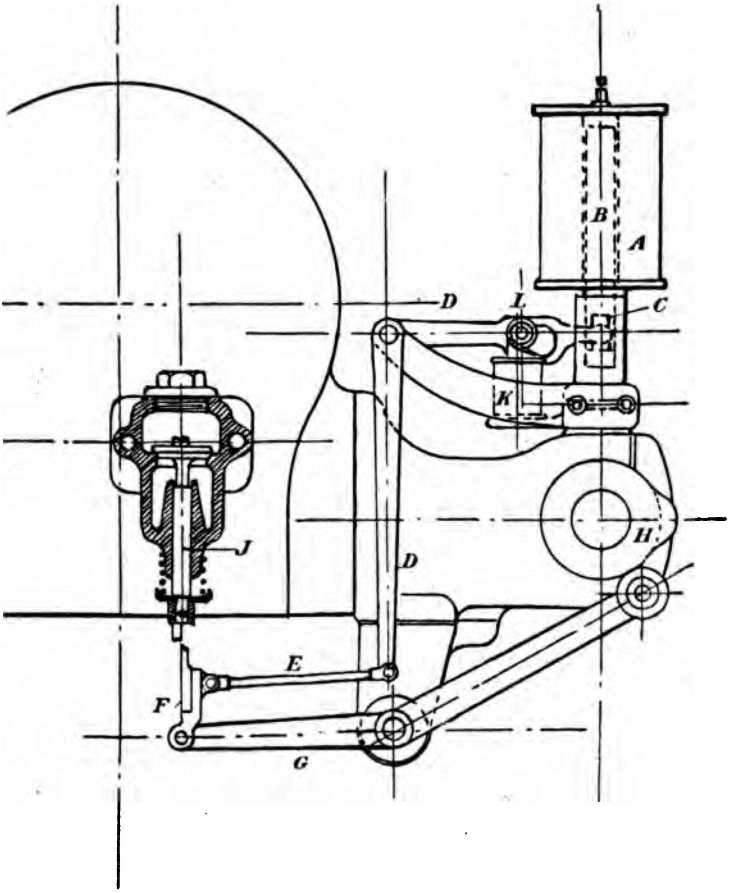


FIG. 188.—RICHARDSON ELECTRIC GOVERNOR, ROBEY ENGINE.

from the dynamo gradually increase, the coil A becomes excited, forming a powerful electro-magnet holding up the core B. Should the required voltage be exceeded, the current through the coils A increases, pulling the cores up slightly, thus drawing the pecker away from the gas valve spindle, and no gas is admitted to the engine. The electric pressure falls with the speed of the engine, and the cores are not pulled so far up, allowing the pecker F to come into action and admit gas. In case the main circuit is broken, or the load thrown off the engine suddenly, the safety electro-magnets K release the pin and roller L, and the cores instantly drop to their lowest position, pushing the pecker F beyond the valve spindle J, and thus stop the engine. This electric governor is extremely sensitive, and the speed of the engine can be regulated by a variable resistance in circuit with the solenoid winding.

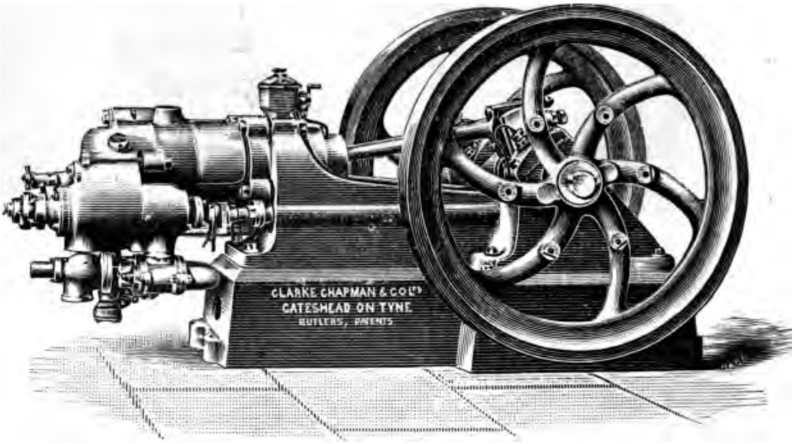


FIG. 189.—CLARKE-CHAPMAN GAS ENGINE.

The **Gas Engine** made by Messrs. CLARKE, CHAPMAN and COMPANY (Butler's patent) works on the four-stroke cycle. Fig. 189 is an external view, and Fig. 190 is a sectional diagram of the parts with a vaporiser added for the oil engine.

One feature is the slowly rotating circular distributing

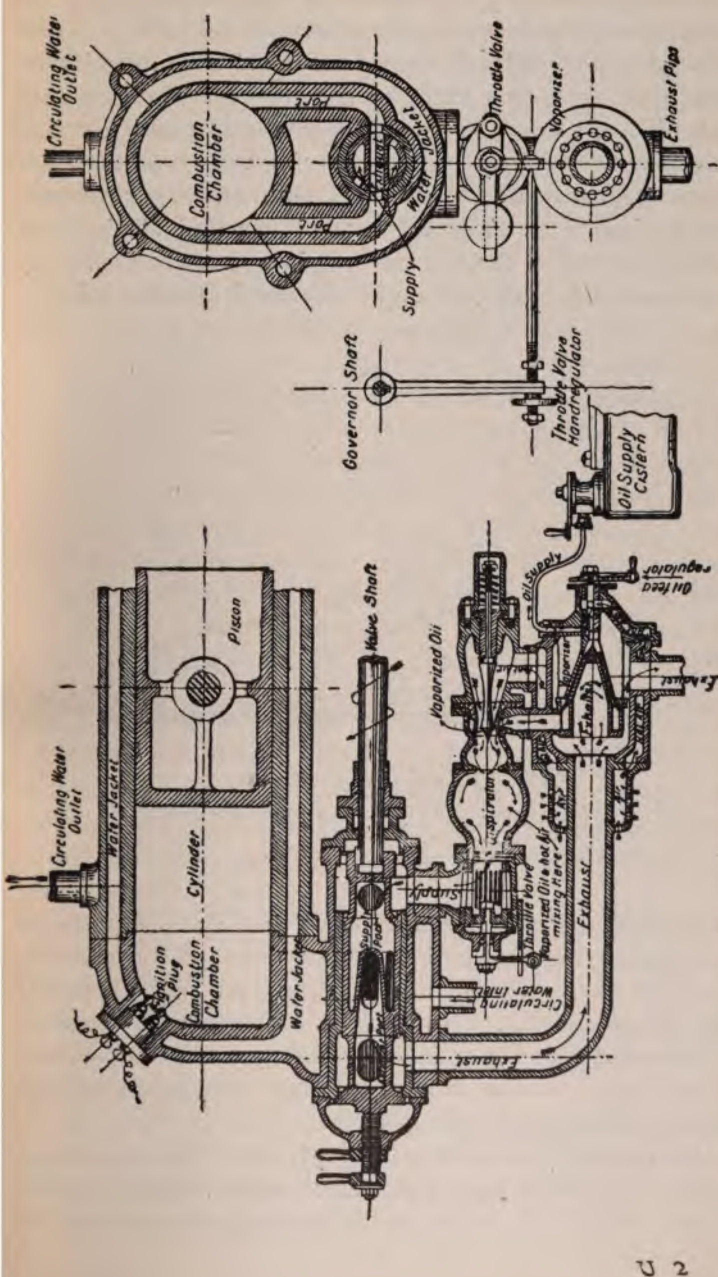


FIG. 190.—CLARKE-CHAPMAN GAS AND OIL ENGINE. DIAGRAM OF PARTS.

valve with two charging or supply and two exhaust ports or slotways across its surface to the combustion chamber. This circular or conical valve is rotated by the side shaft, which is driven from the crank-shaft by a worm and wheel geared 1 to 4. The air supply passes through a nozzle and the gas supply is admitted by a screw regulating valve, and through an annular space around the air nozzle into a mixing chamber, called an inspirator. The mixture of gas and air is then admitted through a throttle valve as in a steam engine, controlled by a weight governor on the fly-wheel, into the cylinder by the supply ports of the circular valve. The compression of the charge before ignition ranges from 50 lb. in small sizes to 75 lb. per square inch in the larger engines at full load. When the charge is throttled by the governor, less of it is admitted into the cylinder, giving a lower compression and explosion. There is an explosion every cycle at any load from full power to running light.

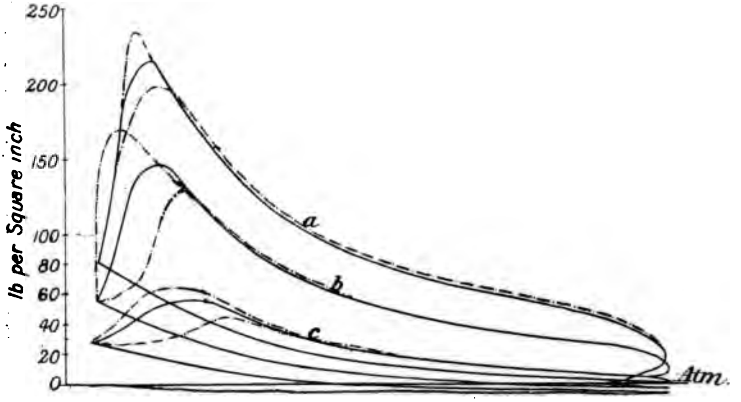


FIG. 191.—INDICATOR DIAGRAMS. CLARKE-CHAPMAN GAS ENGINE.
Cylinder 15" diameter by 22" stroke.

a, Full load, 43 Brake H.P.	at	155	revs.	per	minute.
b, Half load, 23	,,	,, 159	,,	,,	
c, Running light at		162	,,	,,	

The indicator diagrams, Fig. 191, show this governing action. The dotted lines give the extreme variation of the *explosion* curves at each load. Although this method of governing may give regularity of speed, it must be at the cost of large gas consumption, because experience has abundantly proved that increase in compression means increase in economy, other things being equal. Ignition is either by heated tube fixed over the valve casing, or by electric spark from an induction coil and battery with timing commutator fixed on the valve shaft. Taking gas at 1*s.* 8*d.* per 1000, the electrical method is found to work out somewhat the cheaper.

Engines of 14 brake horse-power and upwards are *started* by a *hand-pump* with small inspirator, which forces a mixture of gas and air in proper proportions into a chamber connected to the cylinder by a special valve. When the starting charge is pumped into the cylinder it is fired by the burner or electric spark. Benzoline is also used, and fired by electric spark.

This firm make a 35 brake horse-power **combined gas and oil engine,** which can be changed in a short time from using gas to oil while running, when arranged for correct compression by blocks in the connecting rod bearing at the crank.

Messrs. Clarke, Chapman and Co. also designed a vertical three-cylinder engine of a new type to work compound, and to develop about 100 horse-power. In this engine the balanced rotary valve is used to control the working of the three cylinders. Scavenging of the burnt products out of the combustion chambers after each explosion is effected by means of the expansion cylinder piston in order to fit the engine to work especially with producer gas or cheap fuel gas, and develop large powers.

Trials.—At Stoke Newington an experimental plant, consisting of Thwaite's "duplex" reversible producer, with steam and air blast from fan to make gas from common slack coal, and a Clarke-Chapman gas engine of 35 brake horse-power on coal gas, was tested by Mr. George Cawley in April 1895.

In one of several trials of eight hours' duration, the average yield of gas per 1 lb. of cheap slack coal was 43·91 cubic feet. The analysis by Prof. Vivian B. Lewes of this gas made at low temperature gave—

Saturated hydrocarbons = 4·10 per cent.
Hydrogen = 7·33 „
Carbon monoxide = 17·16 „

and the remainder mainly nitrogen with a little carbonic acid gas. The calorimetric value of the slack, as determined by Mr. Horace Allan, was only 6193 B.Th.U. per lb.

The gas engine cylinder was 13⅛ inches diameter by 22 inches stroke, and during a trial of fifteen minutes at 164·4 revolutions per minute, the engine running with gas valve full open, the actual explosions were 82·2 per minute and the brake was 19·48 horse-power. The compression of the charge, Fig. 192, was 65 lb. per square inch, and the explosive pressure 180 lb., giving a mean effective pressure of 45·08 lb. per square inch, and the average indicated horse-power 27·69.

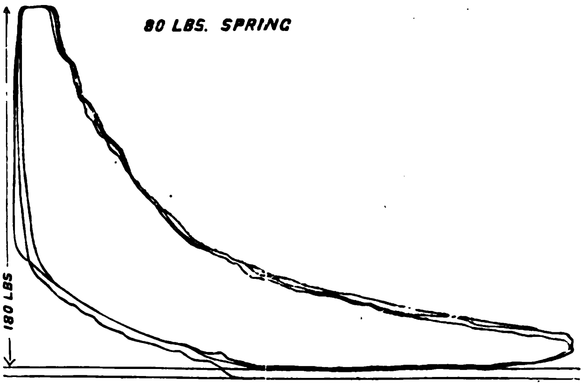
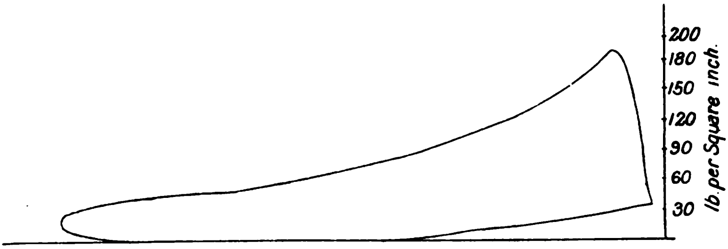


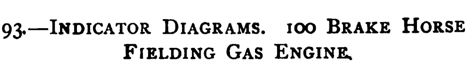
FIG. 192.—INDICATOR DIAGRAM. CLARKE-CHAPMAN ENGINE USING CHEAP FUEL GAS.

The mechanical efficiency of the engine comes to 70 per cent. The consumption of gas by the engine was at the rate of 88·12 cubic feet per indicated horse-power hour, or 126 cubic feet per brake horse-power hour. The slack coal fed into the producer was at the rate of 2 lb. per indicated horse-power hour, including the power required to drive the fan, and 2·9 lb. of slack per brake horse-power hour.

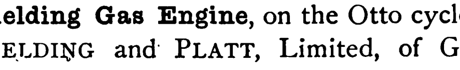
This plant was intended to demonstrate the feasibility of developing power with producer gas made from small slack bituminous coal, coke and peat fuel. It was found that although very good gas was made, the plant was not suitable for practical working over any considerable time. That particular gas engine was afterwards employed to drive the machinery of the boiler shop at the makers' works, where 7 similar engines ran on town gas, some of them having been in use night and day for several years. The makers state that the rotary valve and electric ignition give no trouble.



Load 500 amperes at 125 volts.



Load 100 amperes at 125 volts.



No load diagram.

FIG. 193.—INDICATOR DIAGRAMS. 100 BRAKE HORSE-POWER FIELDING GAS ENGINE.

The **Fielding Gas Engine**, on the Otto cycle, is built by Messrs. FIELDING and PLATT, Limited, of Gloucester, in sizes up to a maximum of about 100 brake horse-power in a single cylinder. The charging and exhaust valves are of the ordinary plain mitre-seated type, fixed in a box forming part of the combustion chamber. Ignition is by hot tube, and all engines, except the very small ones, are fitted with timing valves. All the valves, including the ignition valve, are well water-jacketed. The governor is of the centrifugal ball pattern, loaded with dead weights. The chief feature in the electric lighting engine is the regulation of speed without cut-out of gas, from full load to no load, by varying the amount and richness of the charge. The governor controls two throttle valves for the gas and air inlets, and regulates the quantity and proportions of gas and air in the mixture so that the engine fires a charge in every cycle, even with no load. The light charges have to be fired at low compression, and are made somewhat richer in gas so as render the ignition certain and regular. The indicator diagrams show how the compression and explosion varies with the load. It is said that variation in speed, when the load is thrown off, is under 3 per cent., and the volt meter indicates a cyclical variation of 1 volt. Throttling the admission lowers the compression and must seriously reduce the thermal efficiency of the engine.

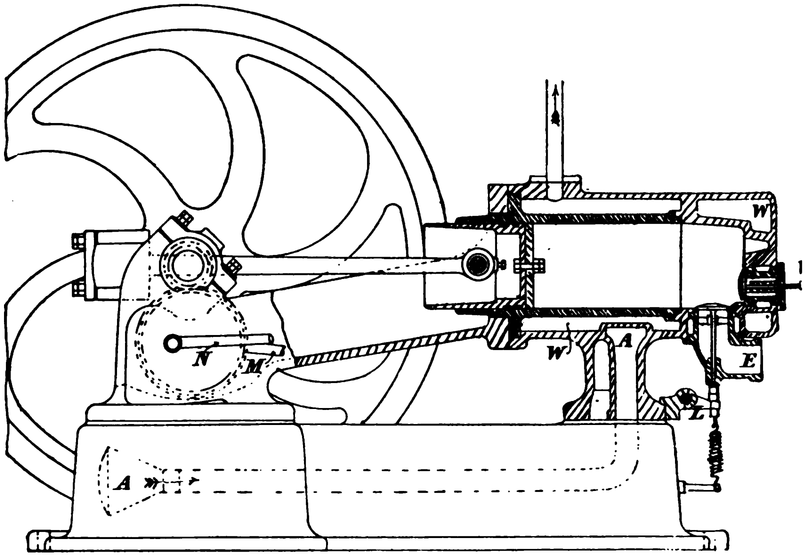


Fig. 194.—Midland Gas Engine (Longitudinal Section).

The **Fielding High-pressure Self Starter** consists of a reservoir into which air is compressed to about 60 lb. per square inch by the action of the piston. To start the engine, the crank is placed about 15 degrees over the near dead centre, gas is admitted into the combustion space until the mixture escaping by an outlet near the flame of the Bunsen burner which heats the ignition tube is shown by the colour of the flame to be practically all gas. Then the outlet is closed, the gas supply shut off, and compressed air from the reservoir is admitted to the cylinder to form an explosive mixture under pressure. This takes up all the slack, and after the piston is moved slowly two or three inches, ignition takes places automatically, when the proper proportions of air and gas are obtained. By this method of starting the sudden effect of the explosion is avoided, seeing the piston is in motion, and driven forward with an average pressure of about 100 lb. per square inch throughout the stroke, which carries the engine through the ordinary working cycle when the explosion at full load gives a mean effective pressure of 80 lb. per square inch.

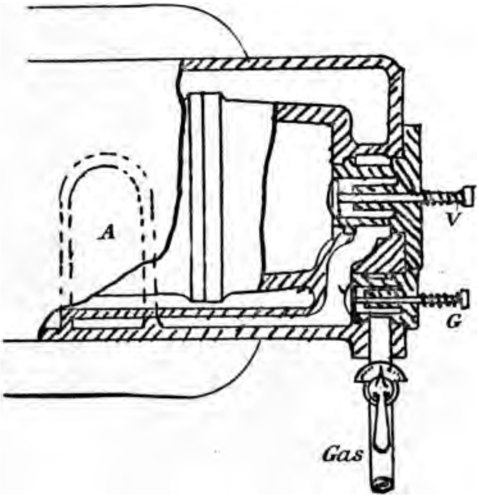


FIG. 195—MIDLAND GAS ENGINE (PLAN).

At King's Lynn Electric Supply Station the dynamos are driven by belt from Fielding and Platt gas engines, each giving 65 brake horse-power at 150 revolutions per minute, with a gas consumption of not more than 85 cubic feet of producer gas (calorific value 145 B.Th.U. per cubic foot) per indicated horse-power hour at full load, and for this only 1 lb. of Welsh anthracite coal is used per hour in the gas producers.

Midland Gas Engine.—THE RAILWAY AND GENERAL ENGINEERING COMPANY, Nottingham, build the Midland gas engine on the four-stroke cycle, in sizes from 1 to 125 horse-power. The "Dot" and some of the small engines are vertical, but the larger ones single cylinder, horizontal, as shown in Fig. 194, a longitudinal section, Fig. 196, a side elevation, and Fig. 195, a sectional plan of the back end of cylinder. The usual side or cam shaft is replaced by a small shaft, geared parallel to the crank-shaft, and the valves are worked by rods and bell-crank levers L and S. Air is admitted through the engine bed A, and mixes with the gas entering at G, before both are admitted to the cylinder by the charging valve V. This inlet valve is opened by a push piece on the bell-crank lever S, Fig. 196, operated by the rod N from the eccentric on the

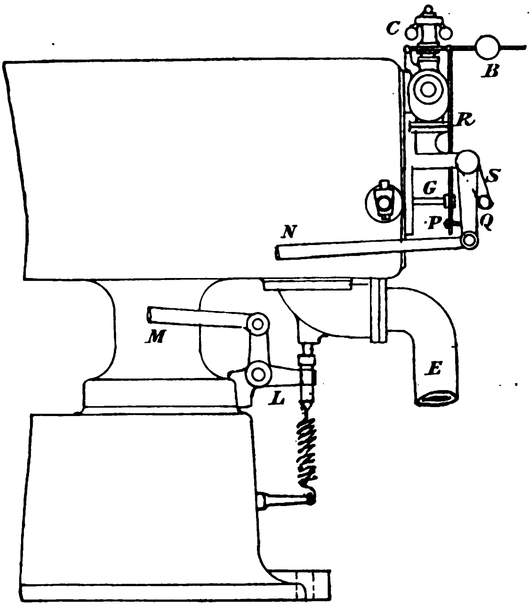


FIG. 196.—MIDLAND GAS ENGINE (SIDE ELEVATION).

auxiliary shaft, Fig. 194. The same shaft also works the rod M and the lever L, to open the exhaust valve E, which is in a separate casting bolted to the side of the cylinder. This exhaust valve is made of mild steel drawn down in one piece to a spindle, which works in a cast-iron bush having a large cooling surface. The belt drive for the governor from the crank-shaft appears to be a weak point in this design, owing to the slipping of the belt. The centrifugal governor C raises or lowers the pecker block P suspended by the rod R, and a stirrup pushes open the gas inlet valve G when the pecker strikes the block Q. The pecker is driven regularly by a lever actuated by the rod N from the eccentric. The centrifugal governor is of the hit-and-miss type, and is regulated by the ball B with a fine screw adjustment.

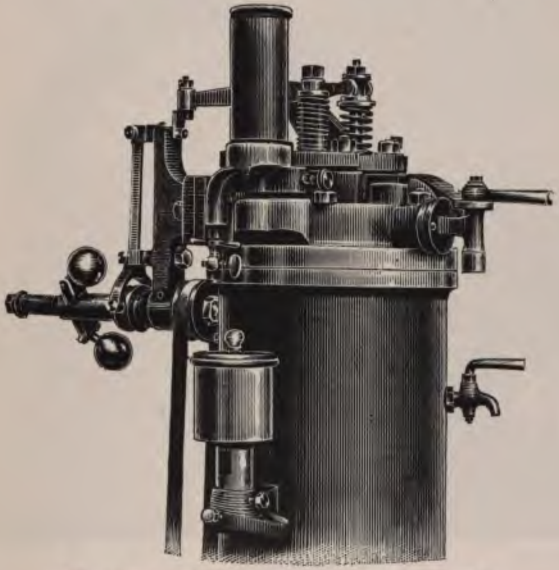


FIG. 197.—CAMPBELL VERTICAL GAS ENGINE.

An engine having cylinder 18·5 inches diameter by 20 inches stroke, develops 125 indicated horse-power at 186 revolutions per minute on coal gas at Nice, where it is driving a dynamo for the electric lighting of the Casino. The compression before ignition of the charge is 85 lb. per square inch above atmospheric pressure, and the mean effective pressure 105 lb. per square inch.

A Midland engine of 4 horse-power at the Eastcroft Gas Works of the Nottingham Corporation, runs 2634 hours in a year, and according to Mr. W. R. Chester, M. Inst. C.E., the gas consumption recorded is at the low and regular rate of 18·8 cubic feet per horse-power hour. The cost of power is just over ½*d.* per horse-power hour.

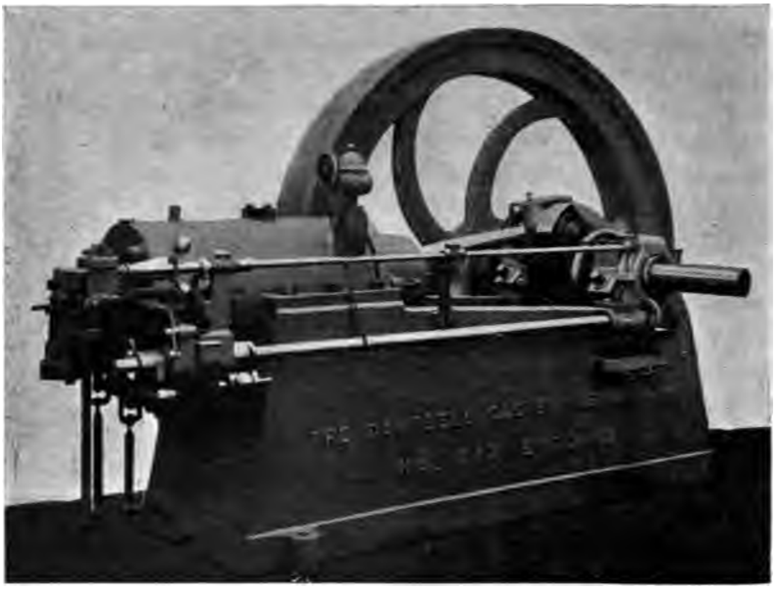


FIG. 198.—CAMPBELL GAS ENGINE.

Campbell.—The CAMPBELL GAS ENGINE COMPANY, of Halifax, England, make an Otto cycle engine (Hugh Campbell's patents). Fig. 197 shows the inverted cylinder of the small vertical type. Ignition is by hot tube. The charging valve is automatic, and is opened by the partial vacuum formed in the cylinder during the down stroke of the piston. The exhaust valve is opened on the up stroke of the piston by an eccentric rod from the crank-shaft, and the pusher acts on a lever attached to the exhaust valve spindle as shown. A peculiarity of the Campbell engine is that in governing the exhaust valve is held open by the action of the ball governor, so that no vacuum is formed in the cylinder to open the automatic gas and air valve, and no charge is admitted; the spent gases in the exhaust pipe are drawn back into the cylinder, and there is no compression on the up stroke of the piston.

The large sizes are built horizontal on the ordinary lines. Fig. 198 is the electric lighting type of Campbell gas engine, giving 35 brake horse-power constant working load, and developing a maximum of 44·5 brake horse-power. It works on the Otto cycle, and in order to reduce irregularities in speed there is one large fly-wheel with an outer bearing for the crank-shaft. The governor is driven direct from the crank-shaft by skew-gear wheels with machine-cut teeth. The crank pin has automatic lubrication for long runs.

Trusty.—THE SHILLINGFORD ENGINEERING COMPANY, formerly Messrs. WEYMAN AND HITCHCOCK, of Cheltenham, make the four-stroke cycle Trusty gas engine in sizes from ½ to 80 horse-power. The nickel ignition tube is turned downwards into the flame, so that the inverted tube is heated close to the ignition chamber. These tubes are said to last about six months.

The valve box is on the side of the cylinder, and the valves can be got at readily by removing the lid of the box. A pendulum governor, consisting of a weight on a small lever swinging on a pivot, controls, by its inertia, the gas valve on the hit-and-miss plan. The Trusty gas engine can be converted into an oil engine by the users, since the parts are made to gauge and interchangeable.

Trial.—In 1892, at the Crystal Palace Exhibition, a Trusty gas engine of cylinder 7·5 inches diameter by 14 inches stroke, running two and a half hours at 201 revolutions per minute, and making 97 explosions per minute, developed 11·9 indicated horse-power, and gave 7·9 brake horse-power, on a consumption of gas 24 cubic feet per brake horse-power hour, including ignition. The gas was assumed to have a heating value of 600 B.Th.U. per cubic foot.

Southall Ideal Gas Engine, made by Messrs. HARDY AND PADMORE, of Worcester, is designed by Mr. J. Southall for small powers from one-man power to 1½ brake horse-power. The cylinder varies from 2¼ inches diameter by 4½ inches stroke to double these dimensions, and the speed from 450 to 300 revolutions per minute. The engine is horizontal and works on the ordinary four-stroke cycle. The cam shaft lies across the back end of the cylinder, and is driven by chain gearing from the crank-shaft at half its speed. Ignition is by heated tube of iron, nickel or porcelain, and a timing valve is used in the larger sizes.

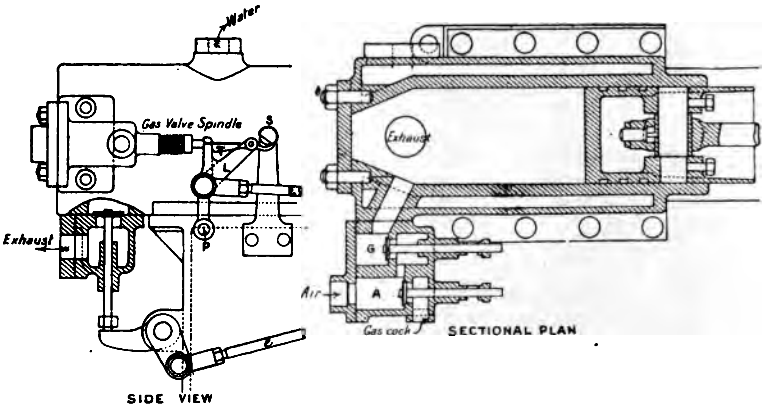


FIG. 199.—GARDNER GAS ENGINE.

Gardner.—Messrs L. GARDNER AND SONS, of Patricroft, Manchester, make small horizontal gas engines, Figs. 199 and 200, varying by half a horse-power from ½ to 7½ brake horse-power, also in larger sizes up to 20 brake horse-power, on the Otto cycle.

The valves are all worked by eccentrics on a shaft driven by gearing at half the speed of the crank-shaft. The opening and closing motion of the valves takes place during a small portion of the stroke of the eccentric, to give the required *amount* and duration of lift. The gas and air are mixed in the chamber G, Fig. 199, containing the gas valve head, in the inlet valve box placed on the side of the cylinder. The exhaust valve is placed underneath the cylinder and worked by the eccentric rod *e* shown in the side view.

The governor is of the inertia type, and consists of a trigger T, Fig. 200, swinging on a rocking lever L, which is moved to and fro about P by an eccentric driven by gear wheels from the main shaft. The inclined stud S is rigidly fixed in a bracket bolted to the engine frame. An adjustable spring tends to keep the trigger down on the stop pin, and affords the means of varying the speed of the engine while running. As the rocking lever approaches the valves, the trigger heel is caught by the inclined face F of the fixed stud S, so that the push piece at the other end of the trigger is tilted upward. If the speed is normal, the trigger falls sufficiently in time for the push piece to engage the stem of the gas valve, and so to open the latter. If the speed of the engine is too high the trigger has not time to fall before the push piece is brought to the valve stem, and, missing it, slides on the top without opening the gas valve. This governor is extremely sensitive, and gives good control of the speed. If the trigger sticks through want of oil it is kicked or tilted up, out of action, and so stops the engine.

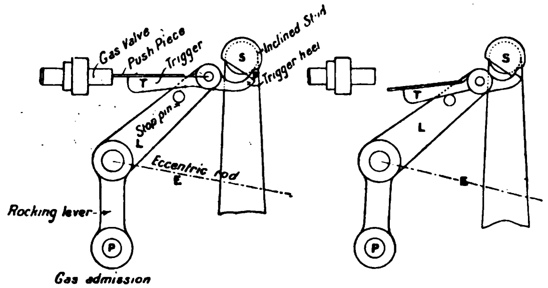


FIG. 200.—GARDNER GAS ENGINE GOVERNOR.

The indicator diagram, Fig. 201, shows the regularity of the pressure in a small engine, giving half a horse-power on the brake at 400 revolutions per minute, the gas consumption being about 20 cubic feet per hour, including that used in the ignition tube burner.

There is a distinct field of usefulness for steady-running gas and petroleum engines of very small power, in driving small machines usually worked by hand.

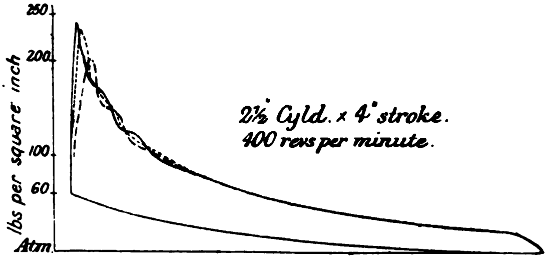


FIG. 201.—INDICATOR DIAGRAM, ½-BRAKE HORSE-POWER GARDNER GAS ENGINE.

Mr. ALBERT BROWN, of Bedford, introduced a modification of the Gardner valve mechanism, Fig. 202. The novel feature of the **Brown Gas Engine** is the method of *governing by holding the air valve open* during the charging and compression

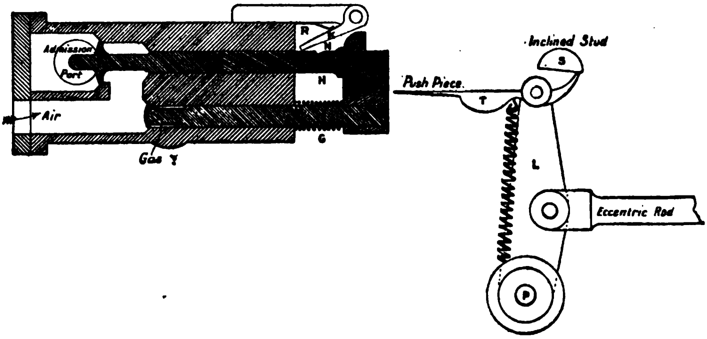


FIG. 202.—BROWN GAS ENGINE (VALVE GEAR AND GOVERNOR).

strokes, when the speed is above the normal; and the gas is cut off at the same time by the action of the governor. When the air valve is opened alone, it is held in that position by a spring R and a pawl or catch K, which engages a notch N in the stem H of the gas valve, and from which it is only released when the pecker is allowed by the governor to fall and engage the sliding block opening the gas and air valves.

This device avoids waste of power in compression and heating of the air, when there is no charge of gas in the cylinder, and the scavenger air clears out residual gases and cools the cylinder for the next charge.

In July 1899 the Author made a 3 hours' test of this little engine, having cylinder 2·75 inches in diameter by 5·5 inches stroke. The engine ran with remarkable steadiness and regularity at any speed from 150 to 300 revolutions per minute, to which it was set by adjusting the governor spring, although the load was increased from one-tenth to upwards of half an effective horse-power on the brake. Prompt ignition is obtained by the hot nickel tube.

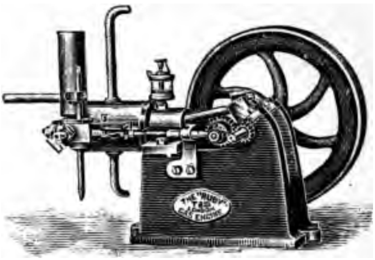


FIG. 203.—RUBY GAS ENGINE, $\frac{1}{12}$ BRAKE HORSE-POWER.

The **Ruby** gas engine, made by Messrs. THORPE AND SALTER, Clerkenwell, London, is a little motor which gives one-twelfth to one-tenth of a horse-power on the brake at 500 revolutions per minute, and consumes coal gas at the rate of 16 cubic feet per hour, at a total cost of about ½*d.* an hour. The trouble is in starting, and keeping the cylinder cool.

The bore of the cylinder is 1·75 inch, and the stroke of the piston 4 inches. The cylinder is water-jacketed and fitted with pipes, Fig. 203, for the circulation of cooling water from a tank. The engine has a little inertia governor, and separate valves for the admission of gas and air, operated by cams on a shaft driven by gearing at half the speed of the crank-shaft. The duration of opening of the admission valves can be adjusted, to suit the quality of coal gas, by a sliding block on the rod operated by the cam. There is also an air suction pipe. Attention must be given to the lubrication of the cylinder and bearings, and the gas supply has to be very carefully regulated. Ignition is by nickel tube heated by a gas burner and enclosed in a chimney with asbestos liner. This gas engine in miniature is said to require a few sharp turns of the fly-wheel to get up sufficient speed to start working on the common four-stroke cycle, and affords an instructive example of the difficulties met with in this type of prime motor.

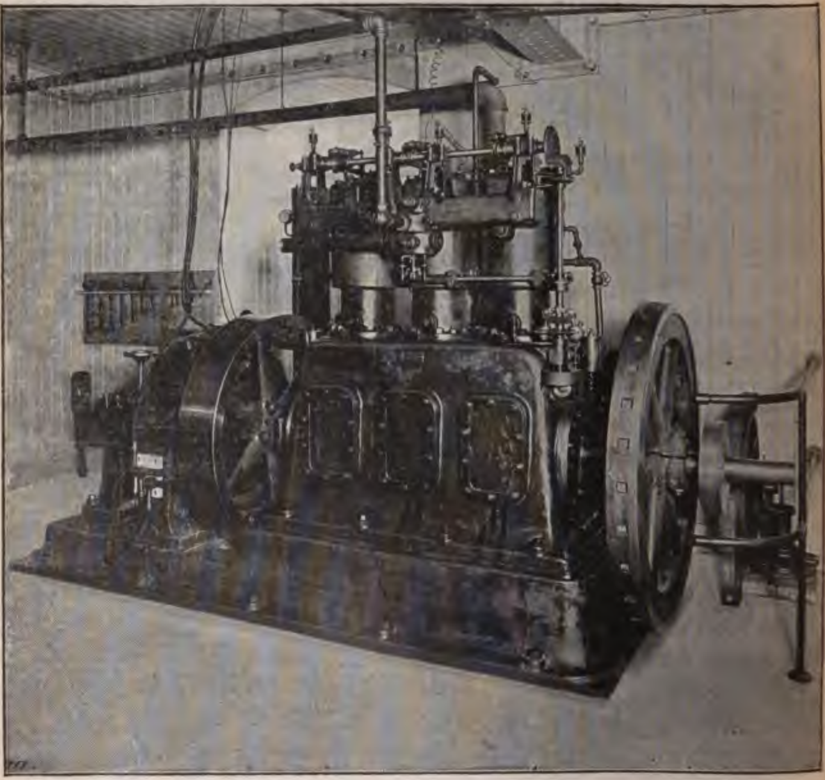


FIG. 204.—WESTINGHOUSE GAS ENGINE, 125 HORSE-POWER.

Westinghouse.—The Westinghouse is a good example of a modern gas engine, similar in design to a vertical steam engine, with enclosed chamber for the cranks and connecting rods, and a heavy fly-wheel at each end of the crank-shaft. The general construction of the mechanism in the 125 horse-power engine is shown by the external view, Fig. 204, and the vertical section, Fig. 205.

The engine has three single-acting cylinders, working on the common Beau de Rochas cycle, with the cranks set 120° apart. An explosion always occurs in each cylinder every two revolutions, so that an impulse is given to the crank-shaft every two-thirds of a revolution *at all loads*.

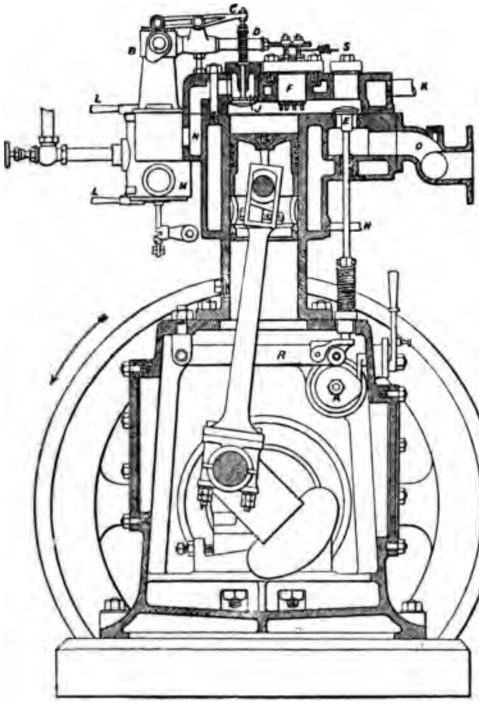


FIG. 205.—WESTINGHOUSE GAS ENGINE (VERTICAL SECTION).

The cam shaft A, Fig. 205, driven by gearing from the main shaft, drives the cam shaft B at the top by bevel gear. and a vertical shaft carrying the centrifugal governor, Fig. 204. The exhaust valve E is held on its seat by the spring which presses the stem of the valve on the plate at the end of the guide lever R, and keeps the roller against the cam. The top shaft B has two cams for each cylinder: one cam opens the admission valve J by means of the lever C, and the other works a horizontal plunger D to break the electric circuit through the wire S at the terminals of the igniter plug F. The electric igniter F is duplex, with two pairs of terminals, so that the wire from the battery can be changed to either pair while the engine is running, or both can be used at the same time, ensuring the ignition of the compressed charge. The cooling water enters the jacket by the pipe H, flows up around the cylinder and leaves at K.

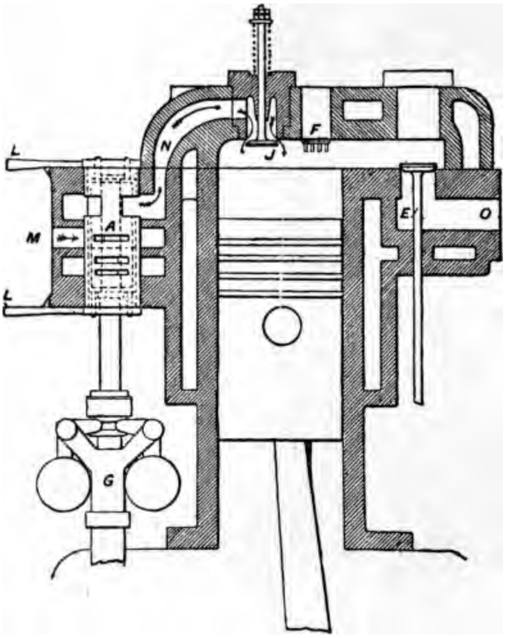


FIG. 206.—WESTINGHOUSE GOVERNOR AND MIXING VALVE.

The gas and air enter the chamber M through the *mixing valve* A, Fig. 206, which can be set for the proper proportions. The upper lever L controls the gas supply and the lower L the air supply, and the scales on the graduated arcs indicate the exact proportion of air to gas in the charge. The speed of the engine is regulated by the **governor** G, Figs. 204 and 206, throttling or varying the amount of the explosive mixture admitted to the cylinder at N, to suit the load, by changing the area of the ports A opened in the mixing valve without varying the proportions of gas and air.

The *action of the engine* can readily be followed from the position of the piston, shown in Fig. 205, just after the compressed charge has been fired in the clearance space.

The pressure of the explosion drives the piston down to the end of its stroke, giving the crank half a turn. Throughout this working stroke the cam A turns one-fourth of a revolution, and near the end of the stroke lifts the exhaust valve E, giving release before the up stroke of the piston, during which the products of combustion escape through the exhaust pipe O. At the beginning of the next down stroke the exhaust valve E is closed and the admission valve J opened, by means of the lever C and the cam B. The mixture of gas and air is drawn into the cylinder from the mixing valve chamber and passage N, Figs. 205 and 206. On the return up stroke of the piston the valve J is closed, and the charge is compressed into the clearance space, ready for firing by the electric spark from the igniter plug F when the piston turns and is again driven down.

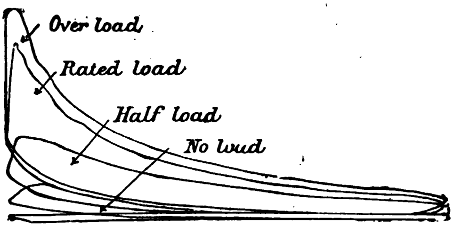


FIG. 207.—WESTINGHOUSE INDICATOR DIAGRAMS.

The amount of the explosive mixture in each charge, and consequently the force of the explosion, is regulated according to the load on the engine.

The variation of pressure in the cylinder, in this method of *governing by throttling the explosive mixture of gas and air*, is clearly seen by the indicator diagrams, Fig. 207, when using rich natural gas. As the load is reduced, a smaller charge of gas and air is admitted, to mix with the products of combustion left in the clearance space, so that the compression is lower and combustion takes place more slowly, with less heat and pressure developed. The difficulty is to ignite the charge, and burn it thoroughly and efficiently when working with poor gas of variable quality at less than the rated load.

The engine is *started by compressed air* stored in steel cylinders at a gauge pressure of 160 lb. per square inch. One of the cylinders of the engine can be converted into a single-acting compressed-air engine, independent of the other two cylinders.

By turning a screw on the end of the upper cam shaft the cam B is thrown out of action, and the admission valve J of one cylinder remains closed. A hand lever, seen on the outside of the crank case, Fig. 205, throws the ordinary exhaust cam A out of gear, and then a double-acting one opens the exhaust valve E on every up stroke of the piston. Another cam on the lower shaft A operates the starting valve on a pipe from the compressed-air reservoir, and is set or timed to admit compressed air through a check valve into the cylinder on every down stroke of the piston. In order to start the engine, bring the crank into the position shown in Fig. 205, turn on the compressed air, and the one cylinder works like a single-acting compressed-air engine. The engine is run by air until speed is got up to slightly compress and fire charges of gas and air in the other cylinders, then the starting valve is closed and the cams again brought into their normal position to work the cylinder as a gas engine.

The 125 horse-power engine has three cylinders, 13 inches in diameter by 14 inches stroke, with a clearance space 21·5 per cent. of the cylinder volume. With natural gas, of heating value 1000 B.Th.U. per cubic foot, the best proportion of gas to air is 1 : 12, and from full load to no-load the compression of charge before ignition varies from 90 to 45 lb. per square inch, giving the mean effective pressure from 70 to 15 lb. per square inch at the average speed of 270 revolutions per minute.

In the United States the Westinghouse gas engine is used, direct-coupled and belted, to drive dynamos for electric light and power. Under ordinary working conditions the consumption of natural gas is 10 to 12 cubic feet per brake horse-power hour at full load (see page 613). With higher compression, in the three-cylinder vertical type of Westinghouse gas engine of 125, 310, 650 and 1500 brake horse-power, the consumption of natural gas has been recorded as low as 9 cubic feet per brake horse-power hour.

The 1500 brake horse-power engine has three vertical cylinders, 34 inches diameter by 5 feet stroke, designed to run at 100 revolutions per minute, and is direct-coupled to the alternator. Steady uniform speed is all-important for running dynamos in parallel, especially for polyphase working. It is found that a regulation close enough for electric lighting is obtained with these three-cylinder engines using rich gas.

Poor producer gas of uniform heating value is also suitable, and the best results are obtained when working at nearly full load.

The best everyday practice indicates that the high thermal efficiency of one-third the heat of combustion of the gas converted into work done on the piston, is realised in a good modern gas engine. **An efficient gas-producing plant and gas engine can run in regular commercial service on one pound of coal per brake horse-power hour.**

CHAPTER X.

OTHER MODERN GAS ENGINES.

THE **Simplex Motor**, of E. DELAMARE-DEBOUTTEVILLE and LÉON MALANDIN, so called from the simplicity of its working parts and general action, was made by Matter et Cie. of Rouen. M. Delamare-Deboutteville * was the pioneer in designing the largest single-cylinder gas engines working on the Beau de Rochas or four-stroke cycle, all horizontal and single-acting, with ignition by electric spark. He was the first in France to use cheap fuel gas. In 1885 a Simplex engine at Rouen worked with Dowson gas. In 1887–88 he also discovered the method of starting large gas engines by introducing the explosive mixture into the cylinder when the piston is set over the centre on the third or explosion stroke, and then firing the charge to drive the piston forward with enough force to start the engine. Another great advance, in 1898, was the 200 brake horse-power single-cylinder Simplex engine made to work continuously and successfully with poor blast-furnace gas of variable quality. This application on a large scale must be of great importance in this country, essentially metallurgical, on account of the future utilisation of these waste gases for power purposes.

The dimensions of the large single-cylinder *Simplex Motors* are :—

Type Simplex	Brake or Effective Horse-power.	Fuel Used.	Diameter of Cylinder.		Stroke.		Speed, Revolutions per Minute.
			Millimetres.	Inches.	Millimetres	Inches	
1888	100	Producer Gas	575	22·64	950	37·4	100
1893	250	Producer Gas	870	34·25	1000	39·37	100
1898	200	Blast Furnace Gas	800	31·5	1000	39·37	105
1899	600	Blast Furnace Gas	1300	51·2	1400	55·15	90

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* By the death of this distinguished engineer on February 16, 1901, in the prime of life, a career of great usefulness was cut short, and the gas-engine industry suffered serious loss.

Fig. 208 is an end view, and Fig. 209 a longitudinal section of the Simplex motor brought out in 1884. The piston C′ acts on the main shaft directly through the connecting rod C in the usual way. The side shaft D, driven by the gear wheels *a*, *b*, from the crank-shaft, at half speed, works the slide valve F and governor by eccentrics, and the exhaust valve H by cam and roller. The strong spring J holds the exhaust valve S on its seat until it is lifted by the lever H.

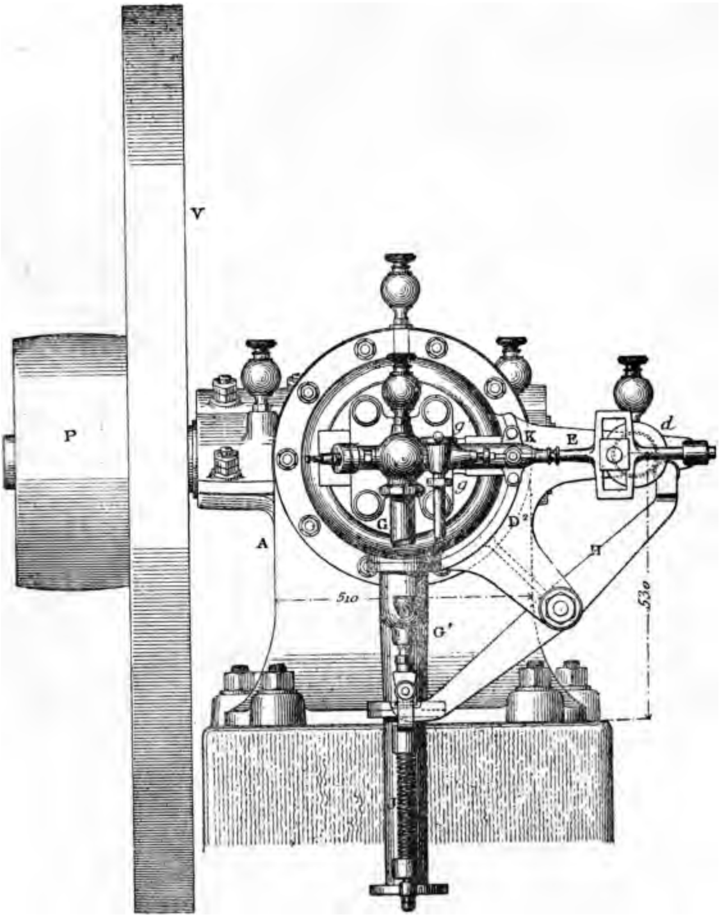


Fig. 208.—Simplex Gas Engine (End View of Cylinder).

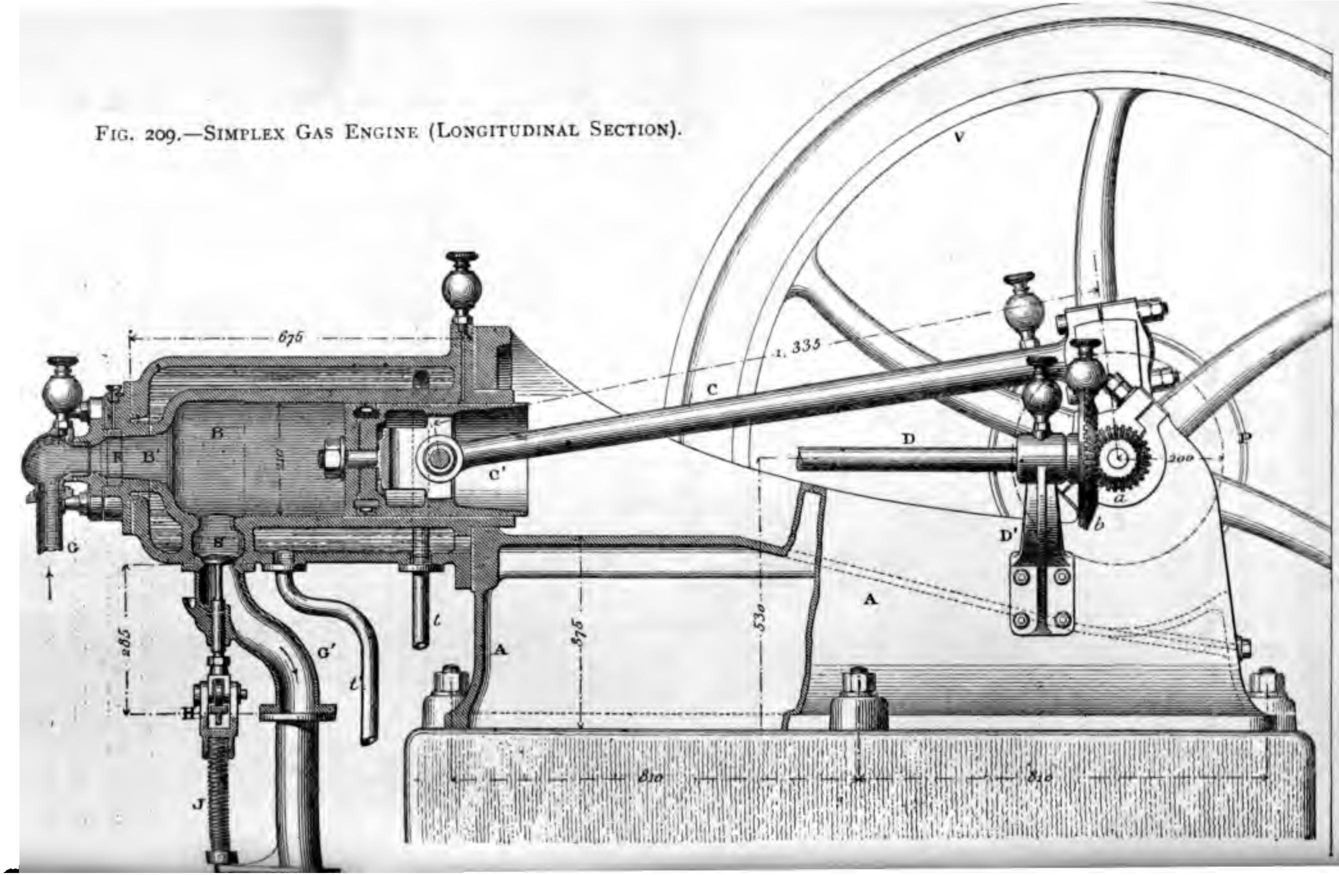


FIG. 209.—SIMPLEX GAS ENGINE (LONGITUDINAL SECTION).

The water to cool the cylinder enters the jacket by the pipe *t'*, Fig. 209, underneath the cylinder, and escapes by the pipe *t* at the top of cylinder. Gas from the pipe *g* is admitted when the valve *s* is raised by the knife-edge *n*, as in Fig. 210, and mixes with air entering by the pipe G in the chamber fixed on the slide cover.

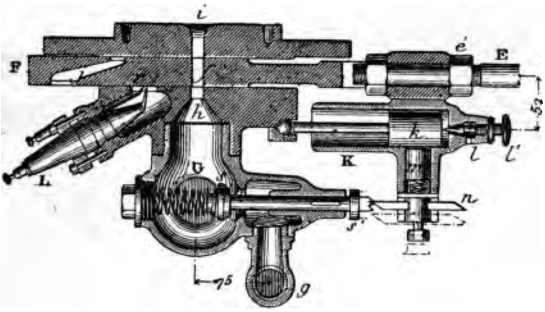


FIG. 210.—ADMISSION MECHANISM.

During the *charging* stroke of the piston the gas and air are sucked in through the conical channel *h'* tapering to a rectangular passage, and thus, *thoroughly mixed*, go through the slide-valve port *f* and by *i* into the compression chamber B', Fig. 209, at end of cylinder.

The *slide valve* F is of simple construction, being merely a cast-iron plate pierced with two holes, Fig. 211, the one *f* rectangular, for admission of the charge, and the other opening *j* (Figs. 210 and 212) oblique with horizontal groove for ignition purposes. On the return stroke the charge is highly *compressed* in the combustion chamber, and the explosion takes place when the piston has passed the centre.

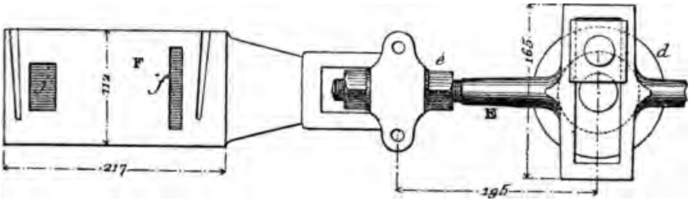


FIG. 211.—FRONT VIEW OF SLIDE VALVE.

Ignition.—A porcelain insulator L is placed in the cover plate, and in a small recess, Fig. 212, electric sparks play continuously between the platinum points *p* connected with the secondary circuit of an ordinary Ruhmkorff induction coil, the primary of which is excited by a bichromate of potash battery.

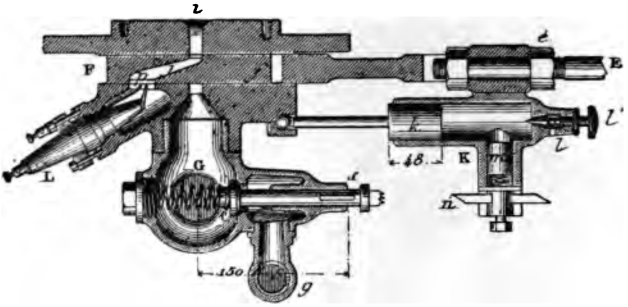


FIG. 212.—IGNITION OF COMPRESSED CHARGE.

As the edges of the oblique passage *j* in the slide F come up to the admission port *i* of the cylinder, the compressed charge drives the burnt gases out of the combustion chamber by a small hole to the outer air, and in position Fig 212 the

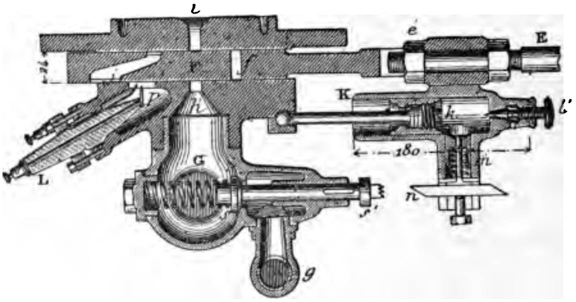


FIG. 213.—EXPULSION OF BURNT PRODUCTS.

fresh charge is ignited by the electric sparks. The expulsion of burnt products by the compressed mixture takes place in about $\frac{1}{150}$th of a second, and owing to the high igniting power of the spark, the compressed charge, even of poor gases, is fired with certainty and precision. By this arrangement, which facilitates lubrication, the slide is not much heated, and with ordinary attention will work a year without needing any repairs.

During *exhaust* the slide valve and ports are as shown in Fig. 213, whilst the exhaust valve S, Figs. 208, 209, is raised and kept open by the lever H actuated by the cam on the side shaft.

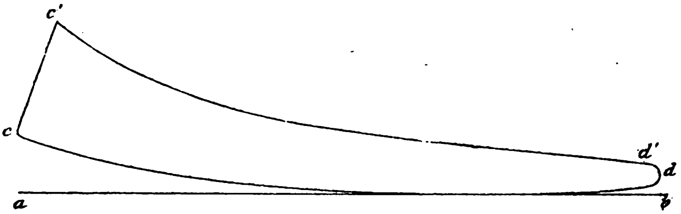


FIG. 214.

The *cycle* of the SIMPLEX engine can be readily followed by reference to the indicator diagram, Fig. 214.

a, *b*, *suction* or *charging* below atmospheric line.
b, *c*, *compression* of charge.
c c' d', *ignition*, *explosion* and *expansion* or working stroke.
d' d a, *release*, *exhaust* or *expulsion* of burnt products.

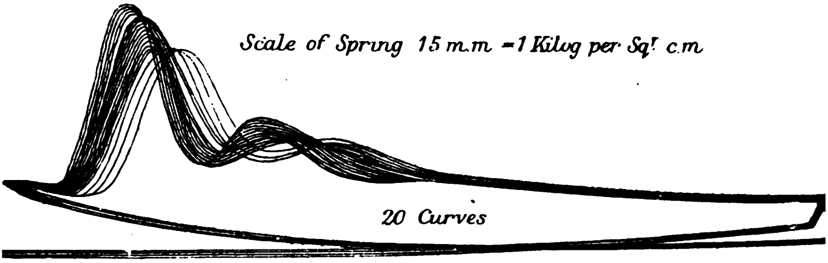


FIG. 215.—INDICATOR DIAGRAM FROM SIMPLEX MOTOR.

Useful brake 5·68 Horse-power; Gas Consumption 20 cubic feet per brake horse-power hour; Speed 191 revs. per min.

Instead of ignition at the dead point, as proposed by Beau de Rochas, a special feature in the Simplex, when using town gas, is that the charge is fired somewhat later, as in Fig. 215, when the piston has already made part of its outward stroke.

Experience shows that in slightly delaying ignition with rich gas there is a decided advantage both as regards increased effective power on the brake and greater steadiness of running. In the first place, the bearings suffer less sudden shock from the explosions. This renders higher compression of the charge before ignition practicable ; whilst the smaller space thus left between the cylinder cover and piston at the end of its stroke allows only a small quantity of burnt products to remain in the cylinder at the end of exhaust.

However, for poor fuel gas, in which combustion is retarded by the inert constituents, prompt and early ignition is necessary. Producer gas is fired just *after* the piston passes the dead centre, and blast furnace gases *at* the dead point.

Simplex Governors.—To regulate the speed of this engine the supply of gas is completely cut off, air only being admitted during one or more admission strokes when the speed is too high, until the normal speed is reached, and then the charge of gas is again admitted.

The AIR-GOVERNOR, shown in Figs. 210, 212, and 213, consists of a pump barrel K, moving to and fro with the slide on which it is rigidly mounted at E. In this air-pump barrel there is a stationary piston *k*, with its piston rod fixed to the slide cover by two indiarubber washers, to allow of a slightly oblique motion. This air pump communicates with the outer air by a small square hole *l*, which can be closed to any required degree by the micrometer screw *l'* with a conical point. A small piston valve *m* moves freely in a second cylinder fixed at right angles to K. The air compressed behind the piston moves the valve down against a spiral spring, and the valve spindle carries at its end a steel knife-edge *n*, which opens the valve *s* for admission of the gas when the small piston *m* is in position shown in Fig. 210.

By the micrometer screw *l'* the annular opening *l*, Figs. 210 and 212, around its conical point can be adjusted for any required normal speed of main shaft, 200 revolutions per minute, say. Then the side shaft D, with slide F, will be driven at a speed of 100 revolutions per minute, and 100 cylinderfuls of air will be sucked through *l* into the large air pump K in that space of time. The resulting air pressure does not overcome the spring in the small cylinder, and the valve *m* is not moved, whilst the knife-edge *n* hits the push piece *s′* and opens the gas admission valve *s* at each stroke, Fig. 210. Now, if from any cause the speed of the engine increases, more air will be sucked into K per minute, and the extra pressure thus produced will raise the small piston valve *m* and the knife-edge *n*, so as to miss the gas valve stem *s′*, as shown in dotted lines. No gas being admitted, the engine will miss fire, and no impulse will be given to the motor piston until the speed slows down to the normal.

A new arrangement of *air governor* has been adopted. The air pump cylinder is differential, having conical space in the middle, with a regulating screw like *l′* to allow some of the air to escape and thus change the pressure of air behind the piston. The piston rod passes through the pump cylinder, and carries at one end a lever which tilts the knife-edge *n*, otherwise kept horizontal by a spring so as to engage or miss the stem of the gas valve, according as the speed is normal or too high. As shown above, the air pump is worked from the side shaft, which also gives the sliding piece carrying the knife-edge or pusher a to-and-fro horizontal motion. The *air governor* is remarkably sensitive, and keeps the speed of the engines at Seraing very regular, although the blast furnace gas varies greatly in richness. It wears very little, and is specially suitable for gas engines on board ship, or for locomotives, because it is independent of level, and works equally well in any position.

For stationary Simplex engines, M. Delamare-Deboutteville also used a simple form of PENDULUM GOVERNOR.

It is constructed on the principle that the time of vibration of a simple pendulum at any place depends only on the length of the pendulum. This compound pendulum consists of two weights fixed on a rod, with a pivot in the middle carried on a bearing rigidly fixed to the slide cover, Fig. 216. The heavier weight is fixed on the lower part of the stem, and the lighter weight above the bearing can be adjusted by screw and locknuts. This pendulum falls freely by its own weight, so that the *time* taken in falling is always the same for any given length of stem ; and the upper weight is adjusted to make the engine run at any required speed.

Bolted to the slide valve of the engine, and moving to and fro with it, is a frame with two knife-edges, one of which comes against the stem s' of the admission valve s and opens it, whilst the other smaller knife-edge is engaged with the notch in the steel end of the pendulum, holding the swing frame in the horizontal position. Otherwise the larger and heavier knife-edge, with a spring, swings below and fails to open the gas valve, as in Fig. 217. This will take place whenever a slightly accelerated speed of slide valve brings the swing frame back so quickly that the small knife-edge will miss the notch of the pendulum, which always takes the same time to fall.

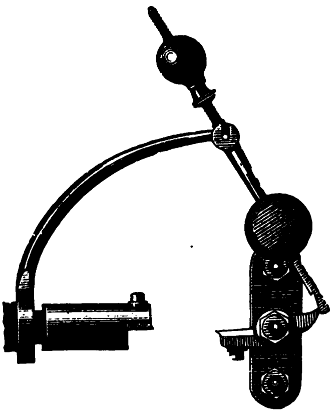


FIG. 216.

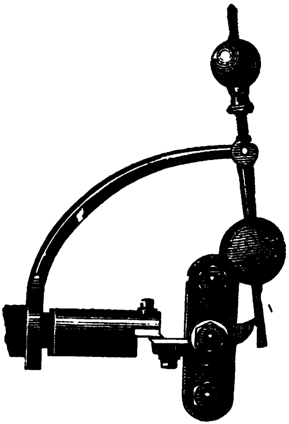


FIG. 217.

SIMPLEX PENDULUM GOVERNOR.

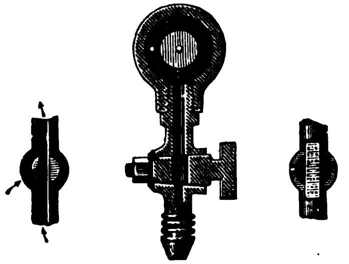
In this way the gas admission valve is left closed and the gas supply cut off; only air being drawn into the cylinder no explosive mixture is formed, and the engine will slow down to its normal speed for want of the usual impulse.

Then the ordinary action of this governor is as follows :—During the back stroke of the slide the small knife-edge engages the notch of the pendulum, which is forced into its highest position. When the slide makes its forward stroke, the small knife-edge being in gear with the notch, the pendulum in its fall brings the swing frame into the horizontal position, the large knife-edge hits the gas valve, opens it to admit the gas, and the explosive mixture is formed.

The small knife-edge and notch hit or miss according to the speed of the engine or slide valve, since the time of fall of the pendulum is always the same.

By this method of governing a powerful explosion follows a miss or cut-out of gas.

The explanation is obvious. When the engine is running light, the governor cuts off the supply of gas, and there are frequent miss-fires, only atmospheric air being drawn in ; the burnt products from previous combustions are thus in great part swept out, and the cylinder cooled, so that when gas is admitted, the mixture being richer, cooler, and undiluted, and therefore consisting of a greater weight of combustible, gives a more violent explosion than usual.



PLAN. SECTION. ELEVATION.

FIG. 218.—THREE-WAY COCK.

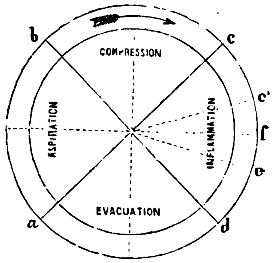


FIG. 219.—CYCLE DIAGRAM.

A simple method of **starting** was devised by the inventors of the Simplex motor. It is only necessary to fit on the igniting apparatus a three-way cock with a small pipe from the gas supply. This three-way cock, Fig. 218, has an oblique hole at its side by which air enters to mix with the gas sucked in through the central opening before reaching the slide-valve port on its way to the cylinder.

In the cycle diagram, Fig. 219, at *c* the piston is at the end of compression before the ignition or inflammation of the charge.

Engines up to 25 horse-power are started from the ignition point *c* as follows. The spark between the platinum points is stopped by the contact-breaker of the induction coil. The three-way cock is opened, and the gas supply cock set to the marked position. The fly-wheel is slowly turned to draw the explosive mixture into the compression chamber in the cylinder, until the point *e* is reached, when the piston has made about two-thirds of its stroke. Now the three-way cock is closed and the main gas cock of the engine set at the position for starting. The fly-wheel is turned backwards from *e* to *e'*, to compress the charge a little. The electric current is switched on, and sparks play between the platinum points, igniting the charge, and the explosion gives the piston an impulse sufficient to start the engine.

Larger engines, over 50 horse-power, are started with greater ease and by another plan, without turning the fly-wheel.

In the engine cylinder, above the compression chamber, a hole is tapped, and fitted with a pet-cock.

The engine must be stopped, not at the ignition point, as before, but *somewhat in advance*, at the point *f*, Fig. 219, with the crank at an angle of 90°, when the piston is at the middle of the explosion stroke. This can be done by barring gear on the fly-wheel.

Now, to start the engine. Open the pet cock at top of the cylinder, and the three-way cock with the gas cock to the marked position. The gas at slight pressure enters the cylinder, drawing in air with it through the small oblique hole in the three-way cock. This explosive mixture drives the burnt products out of the cylinder by the pet cock and fills the space behind the piston. When the cylinder is full of the explosive charge, close the pet cock on top of cylinder, and the three-way cock. Set the main gas cock at the starting position, switch on the electric current to pass the electric spark and fire the charge. The energy of the explosion is sufficient to start the largest engines. Instead of the pet cock an auxiliary cam on the side shaft is also used to keep the exhaust valve open, to release the pressure and allow the gases to escape until the speed is got up.

The Simplex engine runs with remarkable ease, steadiness regularity of speed.

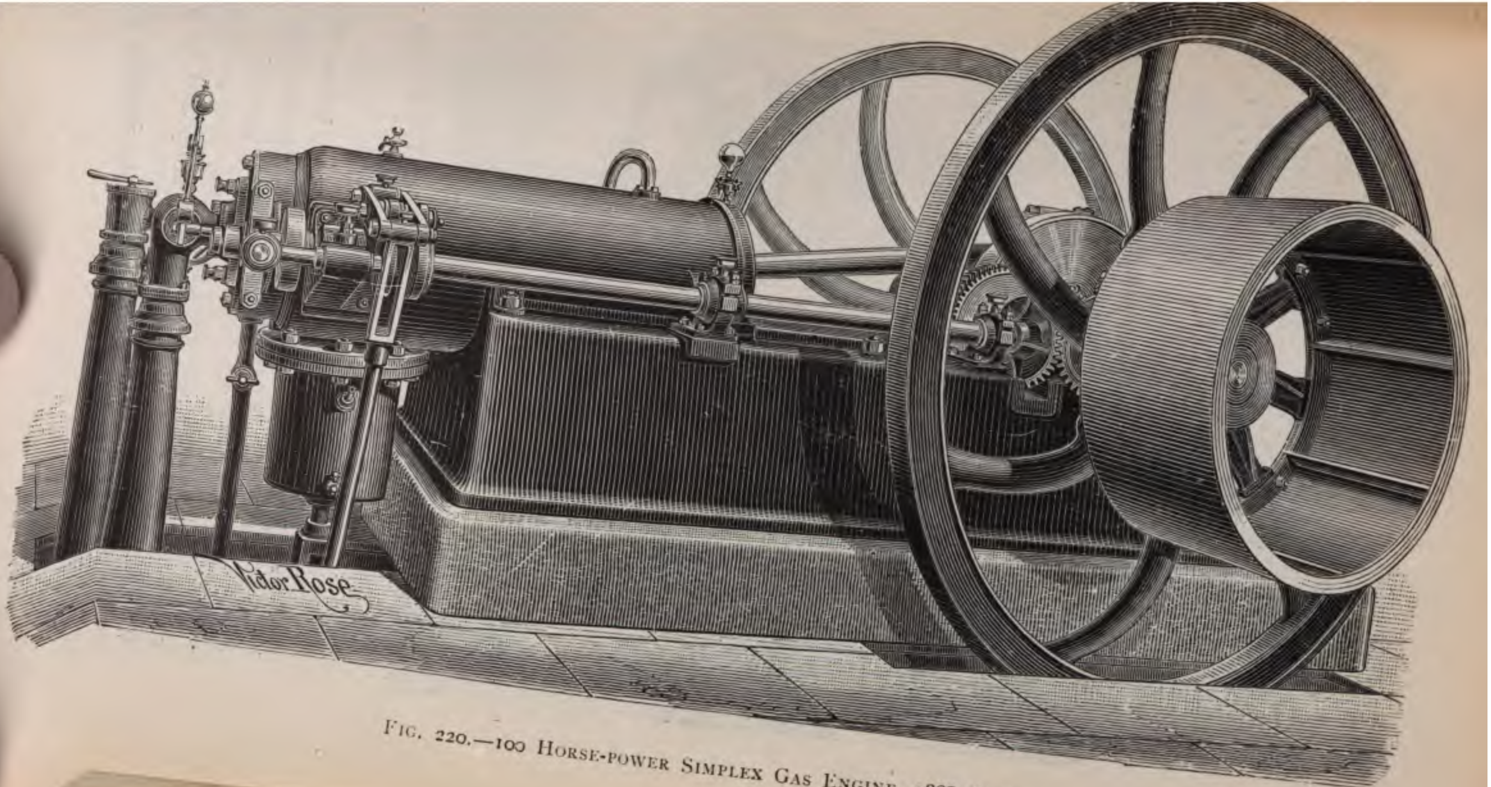


FIG. 220.—100 HORSE-POWER SIMPLEX GAS ENGINE, 1888 TYPE.

In the Paris Exhibition of 1889 a Simplex engine, Fig. 220, of 100 actual horse-power, the largest single-cylinder gas engine then built, worked with Dowson gas of heating value 170 B.Th.U. per cubic foot. The cylinder is 22·64 inches (575 millimetres) in diameter, and the stroke 37·4 inches (950 millimetres). The crank-shaft bearings are long and strong.* A pendulum governor, Fig. 216, keeps the speed about 107 revolutions per minute. The charge, compressed to six atmospheres, is ignited when the crank has turned through an angle of 15 degrees after the piston has commenced its working stroke. The exhaust valve is opened by a cam on

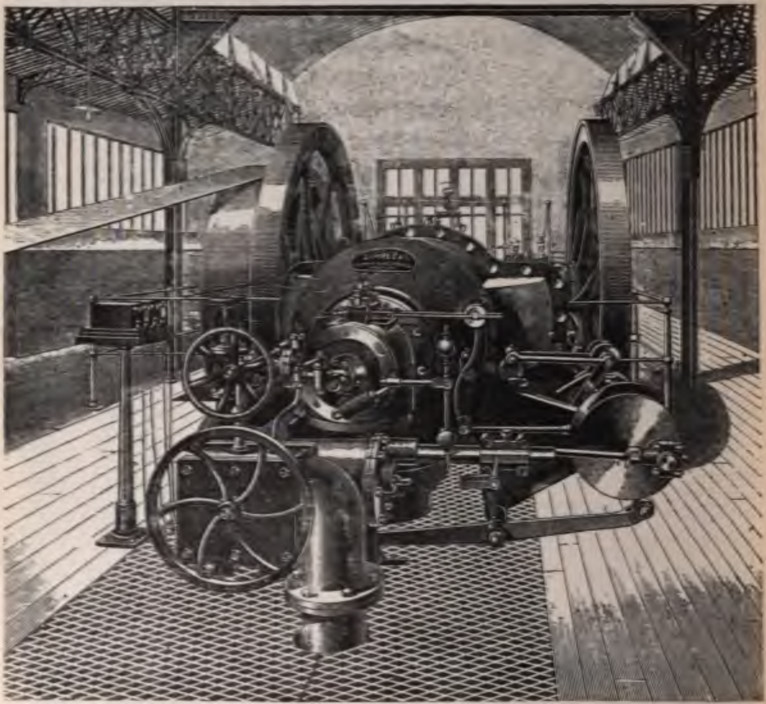


FIG. 221.—250 BRAKE HORSE-POWER SIMPLEX GAS ENGINE, AT PANTIN FLOUR MILLS, PARIS.

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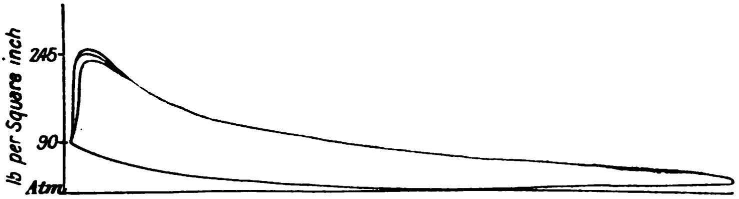
* For drawings of this engine see '*Engineering*,' September 27, 1889.

the side shaft working a long lever with shifting fulcrum, and called the *crocodile's jaw.* The gases are rejected through a large exhaust pipe into a silencing chamber filled with flints and pebbles.

At Rouen, in 1890, Dr. Witz tested this engine, and found it developed 75·9 horse-power with producer gas; consumption of anthracite and coke was (.612 grammes) 1·3 lb. per effective horse-power hour.

In large gas engines the questions of expansion, unequal heating of the cylinder walls, pre-ignitions and prompt firing of the charge of poor gas, cooling of the piston, valves and other organs consisting of large masses of metal exposed to the burning gases, present exceptional difficulties which only long experience and careful design can overcome. In 1893 another step was made from 100 horse-power to the 250 horse-power Simplex engine, designed to run day and night without stop on poor producer gas at the Pantin Flour Mills near Paris. Two Buire-Lencauchez producers used non-bituminous Anzin coal. The gas passed through cooling pipes into a washer, consisting of a column of coke through which water trickles, and next through a purifier filled with dry coke.



'FIG. 222.—INDICATOR DIAGRAM. 250 HORSE-POWER SIMPLEX ENGINE.

Pantin, February 1894. 100 revolutions per minute; diameter of cylinder 0·870 metre; stroke 1 metre.

The end view of the engine, Fig. 221, shows the valve gear and governor. The single cylinder is 870 millimetres or 34·25 inches in diameter, the piston stroke 1 metre or 39·37 inches, and the speed 100 revolutions per minute. All the parts are kept cool by circulating water. The first trial of this engine was made in February 1894; the engine was tested driving the mill 194 hours continuously, at about 280 indicated horse-power, and 220 brake horse-power. Fig. 222 is an indicator diagram taken during the run. The gross consumption of coal was 0·8 lb. per indicated horse-power and 1·04 lb. per brake horse-power hour. The average heating value of the gas was 150 B.Th.U. per cubic foot.

The jacket cooling water was 6100 litres, about 215 cubic feet per hour, or including the producers and washers, the total water used was about 58 lb. per brake horse-power hour. Three months afterwards other trials, made under the same conditions, confirmed these results by giving slightly less consumption.

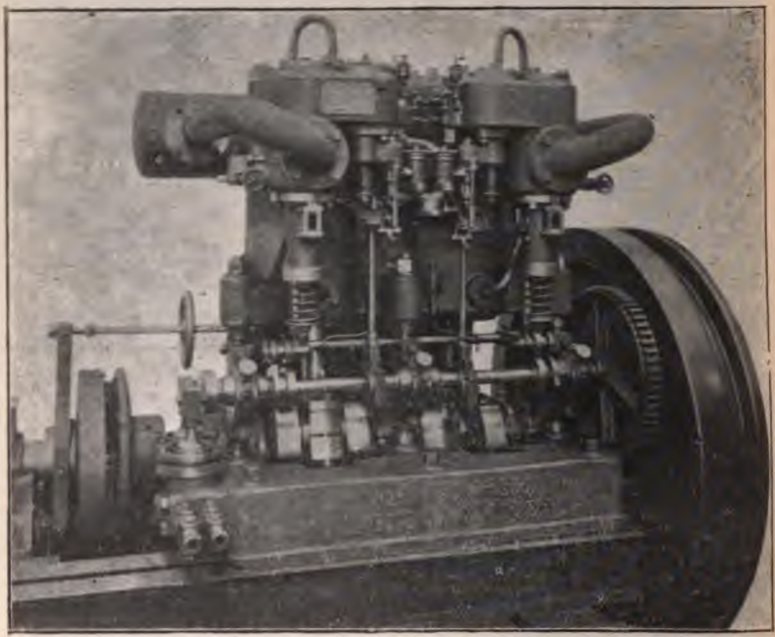


FIG. 223.—40 HORSE-POWER SIMPLEX GAS ENGINE, MARINE TYPE.

Barge L'Idée.—The application of the Simplex gas engine to marine propulsion is seen in the barge L'Idée, Fig. 224, running between Havre, Rouen and Paris on the Tancarville canal. The barge is 30 metres or 98·4 feet long, 5·5 metres

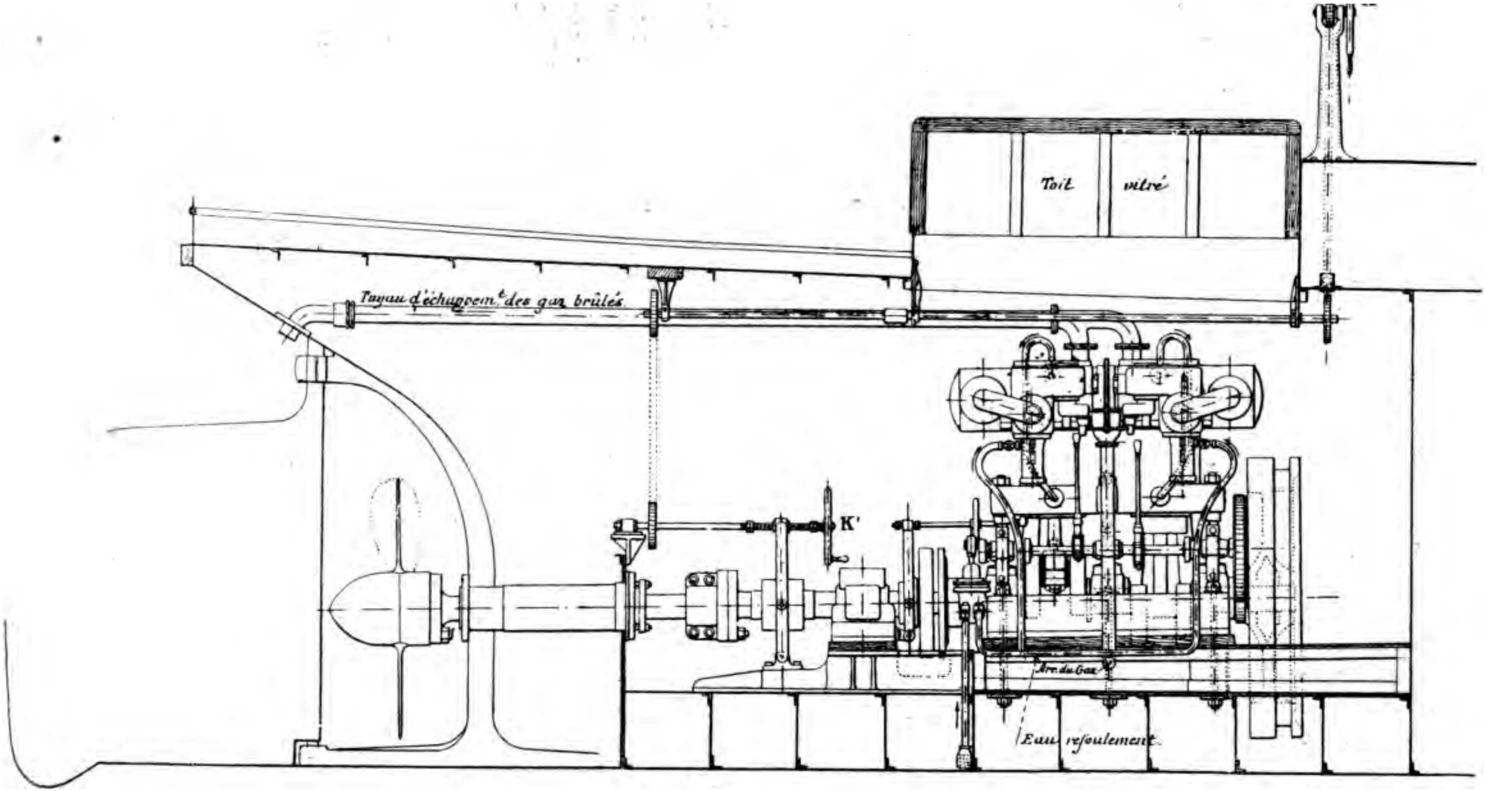


FIG. 224.—BARGE IDÉE FITTED WITH SIMPLEX GAS ENGINE AND MACGLASSON PROPELLER.

wide, and able to carry 250 tons. It is steered by the wheel, shown at K, on the bridge.

The engine, Fig. 223, has two vertical cylinders with cranks at right angles driving the propeller shaft through a coupling, so that the engine may run without moving the screw. A fly-wheel is fixed on the other end of the crank-shaft. The cam shaft is driven parallel to the crank-shaft by gearing, and the gas admission to each cylinder is governed separately. A water circulating pump is worked from the same shaft. Ordinary town gas is used, stored in steel cylinders at a pressure of 40 atmospheres, and supplied to the engine through a regulator reducing it to a suitable pressure. These gas receivers are refilled at the gas works half way between Havre and Paris. By changing the angle of the blades in the MacGlasson screw, Fig. 225, the barge may be propelled full speed ahead or astern, and stopped, without reversing the direction of rotation of the shaft or engine.

In trial trips, June 1894, with 145 tons, the mean speed was about 10 kilometres, that is between 5 and 6 knots (Admiralty) per hour, the engine speed varying from 180 to 250 revolutions per minute. The barge was under complete control even in rough water. The consumption of gas is taken at 650 litres or 23 cubic feet per hour per metric horse-power of 75 kilogrammeters per second, and the heating value of the gas, as found by experiment, 5520 calories per cubic metre, or about 620 B.Th.U. per cubic foot at standard temperature and pressure.

On December 20th, 1895, the **first Simplex engine using blast furnace gas** started at the works of John Cockerill Company at Seraing in Belgium ; it had a single cylinder 7·64 inches (194 millimetres) diameter, and stroke 13·78 inches (350 millimetres), and at 200 revolutions per minute gave 4 brake horse-power during 18 months, running 16 hours every day. Experience showed the advantage of high compression of charge before ignition, and with some modifications this engine developed 8 horse-power on the brake. It worked four months without the cylinder requiring cleaning.

The two difficulties with blast furnace gas were (1) ignition of the charge, and (2) the fine dust carried into the engine cylinder by the gas.

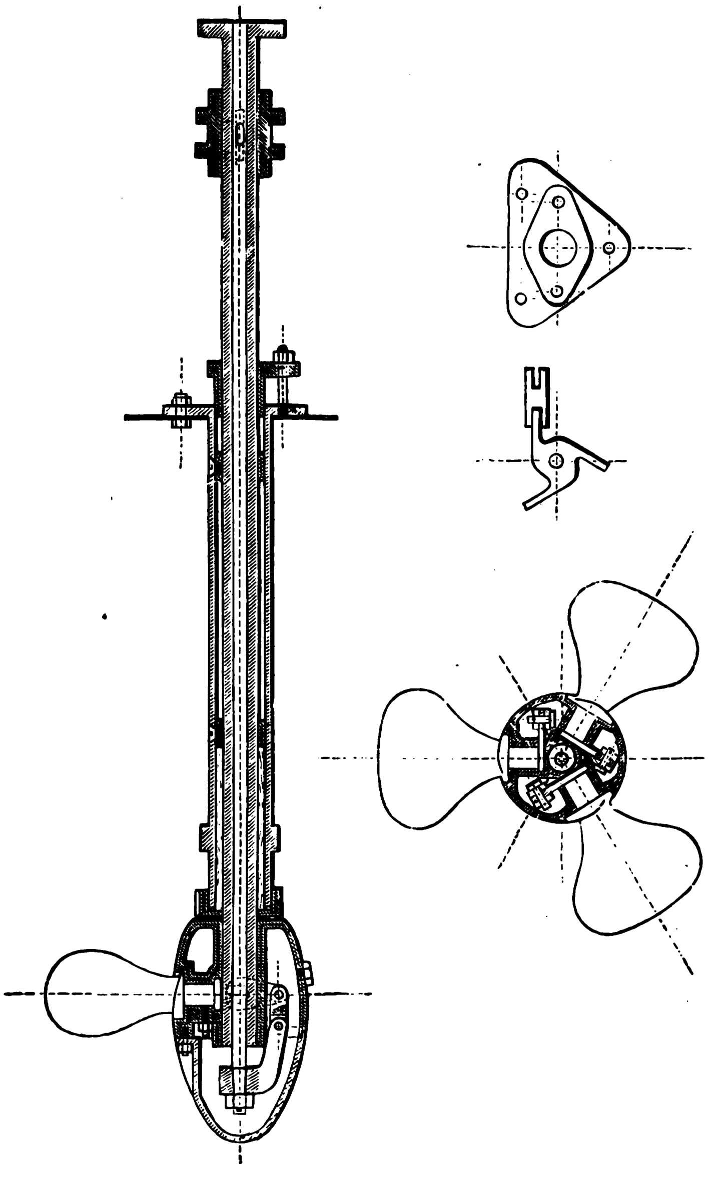


Fig. 225.—MacGlasson Reversible Propeller (Sectional Views).

The gas was sufficiently cleansed, for use in the engine cylinder, by passing through three coke scrubbers washed by a stream of water sprayed on the coke. After running several months the only parts of the engine requiring cleaning were the platinum points of the electric igniter.

At Seraing the gas leaving the blast furnaces carries 10 grammes of dust (blue billy) per cubic metre. Half of the heavy dust is iron, which is returned to the furnaces. About 3 grammes per cubic metre collects in the pipes and is washed away. The remainder, after washing and purification of the gas, amounting to 2 or 3 grammes of dust per cubic metre, is carried into the cylinder of the engine and passed out by the exhaust. The 200 horse-power engine passed through its cylinder 88 lb. of dust daily.

The heating value of the gas from blast furnaces at Seraing, fired with coke, varied from 800 to 1000 calories per cubic metre at 0° C and 760 millimetres, that is from about 90 to 112 B.Th.U. per cubic foot, as found by Dr. Witz in his bomb calorimeter. The little Simplex engine consumed about 5·3 cubic metres (187·2 cubic feet) of this gas per brake horse-power hour.

The results were so satisfactory that a large engine was designed by Delamare-Deboutteville, the diameter of cylinder 31·5 inches, (800 millimetres) and stroke of piston 39·37 inches or 1 metre, to give 200 effective horse-power at 105 revolutions per minute. This engine, Fig. 226, was at work with blast furnace gases, on the 11th April, 1898, driving an air compressor direct for the blast. The exhaust valve is lifted by a lever operated by a cam on side shaft. The speed is kept steady by the sensitive air governor. The charge is compressed to about 115 lb. per square inch, or 8 kilos. per square centimetre, before being fired *at* the dead centre by a continuous stream of electric sparks in a slide valve, Fig. 212. The temperature of the exhaust gases is from 480° to 510° C. The indicator diagram, Fig. 227, was taken when the engine was using the very poorest blast furnace gas.

Trial.—On the 19th and 20th July, 1898, Dr. Witz tested *this engine* under ordinary working conditions, during a con-

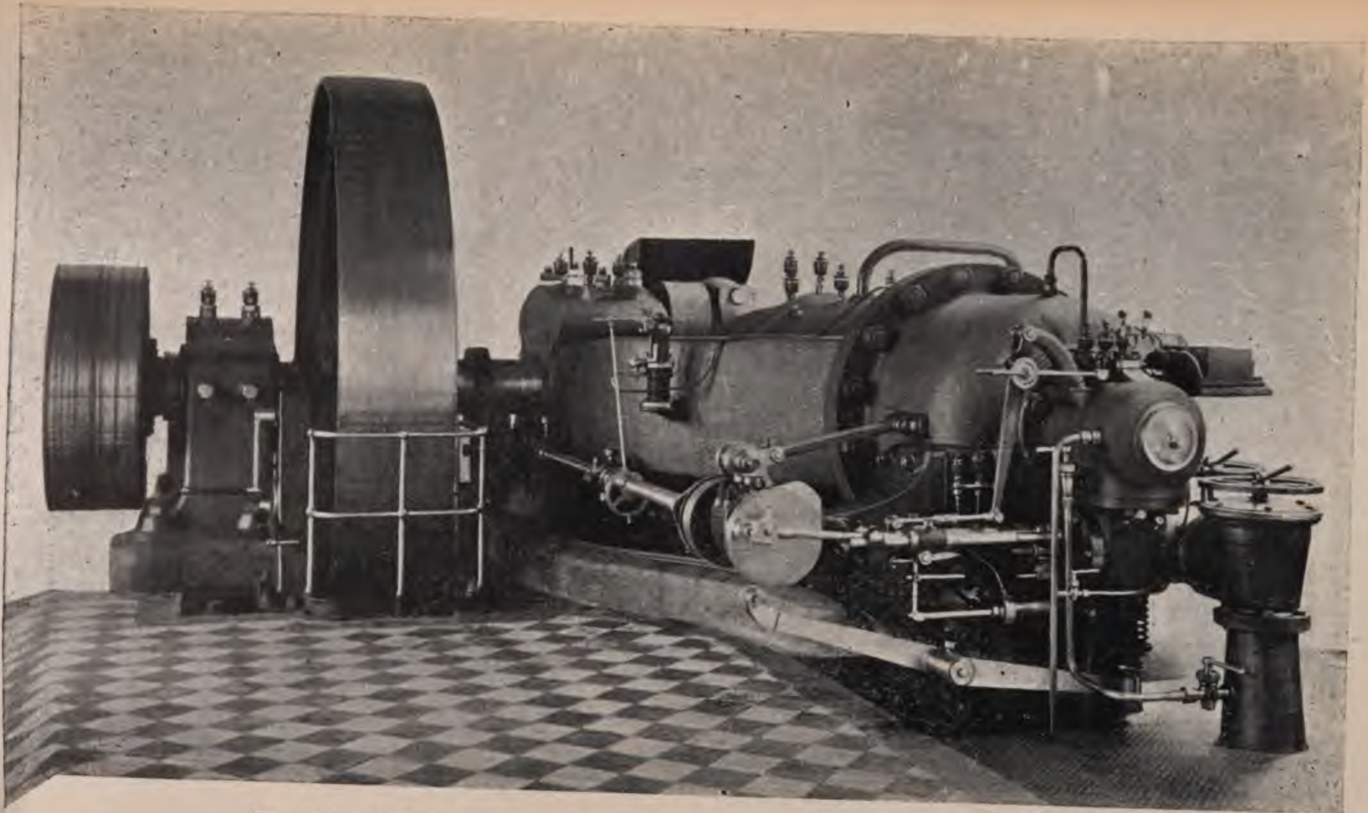


FIG. 225.—200 BRAKE HORSE-POWER SIMPLEX ENGINE USING BLAST FURNACE GAS.

tinuous run of twenty-four hours, at normal load, the governor cutting out one charge in every 10. The gas was supplied by four blast furnaces fired with coke, and taken either direct from the scrubbers or through a gas-holder, 39 feet in diameter and 10,595 cubic feet capacity, graduated to measure the consumption. The gas was thus measured 5 times during periods of 29 minutes each. The power was absorbed on a brake wheel cooled by water on the inside.

Here the effective work done on the brake is equivalent to 19·4 per cent. of the heat of combustion of the blast furnace gas.

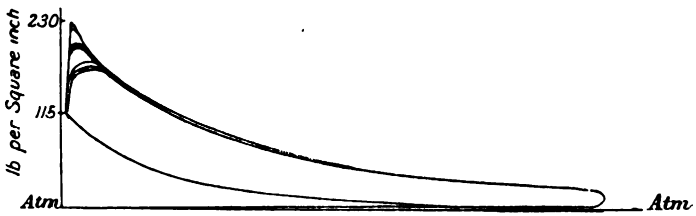


FIG. 227.—INDICATOR DIAGRAM, SIMPLEX ENGINE WITH BLAST FURNACE GAS.

Cockerill Company Works, May 12, 1898. 104 revolutions per minute ; 195 brake horse-power ; 1 miss or cut-out in 15 cycles.

Dr. Witz concludes that the Cockerill Company possess a 200 horse-power engine which gives each *effective horse-power hour* on 3·5 cubic metres (123·5 cubic feet) of blast furnace gas, using about 100 litres (22 gallons) of water and less than 18 grammes of oil and grease. The oil used for the lubrication of the engine was more than two-thirds of a gallon per hour. The speed is as regular as that of a steam engine, and the dust in the gas does no harm for continuous running. At Seraing about half of the gas from the blast furnaces is used to fire the boilers, and the remainder is available for power purposes. It is found that for every 1000 kilos. (2204·6 lb.) of iron produced per day by the blast furnaces, there is gas available to give 2 horse-power during the twenty-four hours.

RESULTS OF TRIAL OF 200 H.P. SIMPLEX GAS ENGINE, USING BLAST FURNACE GAS, JULY 1898.

Duration of full load trial run		24 hours
Revolutions per minute (mean)		105·2
Explosions " "		47
Pressure of charge before ignition	7·5 kilos. per square cm.	107 lb. per square inch
Circumference of brake wheel	4·857 metres	15·935 feet
Effective load on the brake	1595·45 kilos.	3517 lb.
Brake-power	181·16 chevaux	178 6 B.H.P.
Consumption of gas per hour, at 0° C. and 760 mm.	3·329 cub. metres per effective cheval	117·6 cubic feet per metric H.P. 119 cubic feet per B.H.P. (English)
Heating value of gas (including latent heat of steam)	981 calories per cubic metre	110 B.Th.U. per cubic foot
Water used per effective cheval hour:—		
Cooling water through jacket	72 litres	158·4 lb.
Rise in temperature of water.	22°·7 to 33°·7 C. = 11° C.	19°·8 F.
Water to scrubbers	30 litres	66 lb.
Lubricants used in 24 hours:—		
Oil	68 kilos.	150 lb.
Grease	2 "	4·4 lb.

M. Delamare-Deboutteville also succeeded in overcoming the troubles due to the fine dust carried into the engine cylinder by the blast furnace gases. The gas is *cooled* and washed on its way from the blast furnaces to the engine, by passing through a wrought-iron chamber, about 23 feet by 23 feet by 4 feet, placed in the open air and fitted with checker work into which water jets play from four Koerting injectors at the top. The long mains, with bends and changes of level, cool the gas and free it from the heavier dust in deposit chambers and dust catchers. The Cockerill Company have constructed single-cylinder Simplex engines to develop 600 brake horse-power with poor gas, cooled and washed, direct from the blast furnaces, and each engine drives a blower for the air blast. This 6co horse-power engine, Fig. 228, was an important feature of the Paris Exhibition of 1900.

The diameter of the motor cylinder is 51·2 inches (1·3co metre), stroke 55·1 inches (1·400 metre), diameter of piston rod 9·6 inches (0·244 metre), and length of connecting rod 14 feet 5 inches. The crank-shaft is 18·1 inches (0·460 metre) in diameter, and runs at a normal speed of 80 revolutions per minute. The fly-wheel is 16 feet 5 inches in diameter, and weighs 32·5 tons. The engine alone is 11 metres in length, 4 metres in height, and weighs 94 tons.

The plunger piston and every part of the combustion chamber is cooled by water-jacket to keep the temperature of the cylinder low for the admission and compression of a great weight of gas with dust from the furnaces. The charge is compressed to 135 lb. per square inch (9·5 kilos. per square centimetre), and fired by the electric spark. The valves are of the ordinary type, lifted by levers and cams from the side shaft.

To start the engine, winding gear is used to bring the piston over the dead point on the working stroke, a *compressed charge* drives the piston, and the electric ignition cannot work until the starting apparatus is thrown out of gear.

Trial.—During three days in March 1900, M. H. Hubert, Professor of Mines at the University of Liège, in the presence of several engineers, carried out a trial of the 600 horse-power Simplex gas engine driven by cooled gases from the blast furnaces of the Société Cockerill at Seraing, Belgium. The motor tested had been working a blowing engine from November 1899. On the 19th March a preliminary test was made, the engine running without any load, the air pump piston being disconnected. When running light at 67 revolutions per minute, the engine indicated 147 horse-power, and the consumption was 176·5 cubic feet of blast furnace gas per indicated horse-power hour, spent in overcoming the friction of the mechanism.

On the 20th March the power was absorbed by a rope brake on a pulley, cooled internally with circulating water, and coupled direct to the main shaft. The gas was drawn

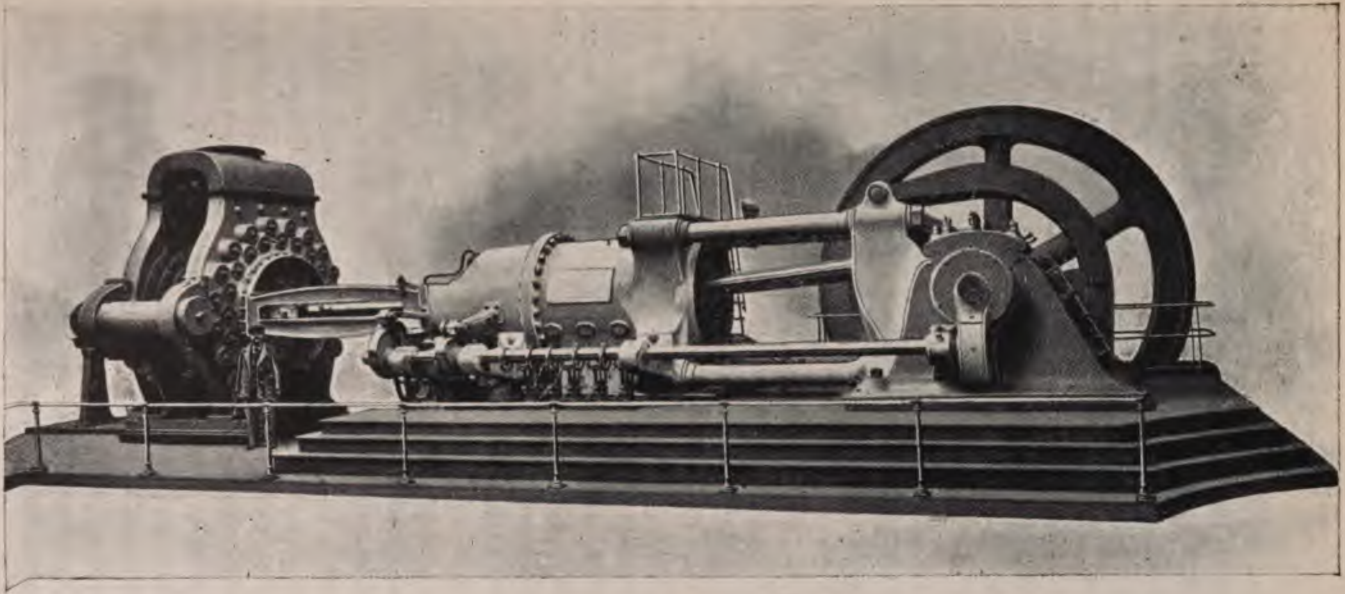


FIG. 228.—600 BRAKE HORSE-POWER SIMPLEX BLOWING ENGINE USING BLAST FURNACE GAS.

from five blast furnaces making Bessemer pig iron, through the large cooling chamber with water from sprays forced by Koerting injectors into the gas-holder calibrated by Professor Witz in the previous test of the 200 horse-power engine.

The heating value of the gas was determined in three ways. 1. During the trial, the gas from the holder was tested in a Junkers calorimeter. 2. A few samples were collected by Professor Witz and taken away to be tested in the special bomb calorimeter in his laboratory at Lille. 3. Several samples were analysed in an Orsat apparatus, and the heating value calculated from the chemical composition.

The temperature and pressure of the gas were taken, also the temperature and weight of the jacket cooling water. The quantity of oil used for lubrication was not measured. A counter on the crank-shaft gave the number of revolutions, and another the number of explosions. The mean of five tests is given in the table (see page 323).

On the third day of trial the motor was run as a blowing engine driving the air pump. At 84 revolutions per minute the air pressure was 7·7 lb. per square inch, and at 94 revolutions per minute the pressure was 8·7 lb. per square inch. The last test was at maximum power and speed, with an explosion every cycle.

The distribution of heat at maximum power is: heat turned into work done on the piston 28 per cent.; lost in jacket water, 52 per cent.; and carried off by exhaust gases and other losses 20 per cent. unaccounted for.

Double-cylinder tandem simplex engines of 1200 horse-power, and two tandem engines on each side of dynamo of 2500 horse-power are built by the Cockerill Company.

In the year 1895 the **Oechelhäuser** gas engine was designed for the utilisation of the waste gas from blast furnaces at the Hörde Ironworks, Westphalia. This large horizontal engine has one long motor cylinder with two pistons moving in opposite directions, like the Atkinson "differential," and a double-acting pump driven from the back cross-head. The back piston rod works directly on the cross-head, the ends of *which* are bolted by side rods to slides and connecting rods

RESULTS OF TRIAL OF 600 HORSE-POWER SIMPLEX GAS ENGINE, USING BLAST FURNACE GAS. March 1900.

Date of Trial	20th March	21st March.	
Revolutions per minute (mean) . . .	94	84	93
Explosions ,, ,, . . .	42	36	46·5
Indicated horse-power	790	746	886
Brake horse-power	573	Air 562	Air 725
Mechanical efficiency, per cent. . . .	72·5	75·4	81·8
Consumption of gas per hour:—			
Per indicated horse-power (cubic feet)	89·8	82·5	82·4
Per brake ,, ,, ,,	123·7	110	100·8
Heating value of the gas in B.Th.U. per cubic foot	102·5		
Junkers calorimeter ,, ,, ,,	96	98·7	99
Witz bomb calorimeter ,, ,, ,,	110	111	111
Thermal efficiency:—			
Heat turned into work in cylinder, per cent.	27·2	30·9	30·6
Heat turned into work on brake, per cent.	19·7	Blower 23·3	Blower 25

driving two cranks on the main shaft. There is no valve gear. The two motor pistons, connected to opposite cranks 180° apart on the main shaft, uncover and cover the admission and exhaust ports in the cylinder. Towards the end of the expansion or working stroke, when the pistons are far apart, one of them uncovers the exhaust port and the other uncovers the port to admit scavenging air under slight pressure from the pump, to sweep the products of combustion with dust out of the cylinder.

At the same time the combustible mixture of gas and air is drawn through a mixing valve into the pump, and compressed into the space between the motor pistons when the exhaust port is covered. On the return stroke the pistons coming together compress the charge to a pressure of 8 to 10 atmospheres. At the dead point the charge is fired by the electric spark, and the explosion drives both pistons apart in opposite directions at the same speed, doing work on the crank-shaft. There is one working stroke every revolution, while the double-acting air pump draws in and delivers to the motor cylinder (1) scavenging air by a pipe on one side, and (2) the combustible mixture of gas and air by a pipe on the other side of the cylinder to a separate annular space and port. The speed is regulated by the governor acting on the mixing valve to vary (1) the proportion of gas to air, or (2) the amount of the charge when a greater range of fluctuation of speed is allowable.

The Deutsche Kraft-Gesellschaft build these single-cylinder engines from 300 up to 1500 horse-power.

The 300 horse-power Oechelhäuser engine has one long cylinder 480 millimetres (18·9 inches) in diameter and 800 millimetres (31·5 inches) stroke, with two pistons working on three cranks on the main shaft, besides the double-acting air pump at the back. The engine runs at 135 revolutions per minute. A 600 horse-power engine consists of two single-cylinder engines, each developing 300 horse-power. The mean consumption of blast furnace gas, of heating value 100 B.Th.U. per cubic foot, is said to be about 3 cubic metres (106 cubic feet) per brake horse-power hour, and the cooling water 35 litres (7·7 gallons) per horse-power hour. A single-cylinder engine 1·200 metre (47·24 inches) in diameter can work up to 1500 horse-power if run at 80 revolutions per minute.

Modern Lenoir Engine.—In 1883 LENOIR, the inventor of the first commercial and pioneer gas engine of 1860, brought out a new compression gas engine, Fig. 229, to work on the same cycle as the Otto, though the details of the design are different.

All the operations are performed in one cylinder. The front end of this cylinder is made into a special compression chamber, like a *cartridge*, called the "*reheater*," provided with deep, strong ribs in the casting, exposing a large cooling surface to the air; whilst the water-jacket is only around that part of the cylinder swept by the piston.

The *slide valve is altogether done away with*, and simple mushroom lift valves used instead, for admission and exhaust, worked by levers from cams on the side shaft. This cam shaft is driven by spur wheels at half the speed of the main crank-shaft. The exhaust valve is placed at the base of the *cartridge* or *reheater*, and allows the rejection of all the burnt gases.

The charge is ignited by the electric spark from a Ruhmkorff induction coil, between two points immediately above the admission port. The charge of gas and air is sucked into the cylinder by the piston, and compressed to at least 4 atmospheres pressure in the cartridge at a high temperature, which facilitates ignition, permits the use of poor mixtures, and gives complete combustion. Since the mixture is compressed to 4 atmospheres before ignition, the maximum explosion pressure reaches 12 or 13 atmospheres, and this is followed by a long range of expansion.

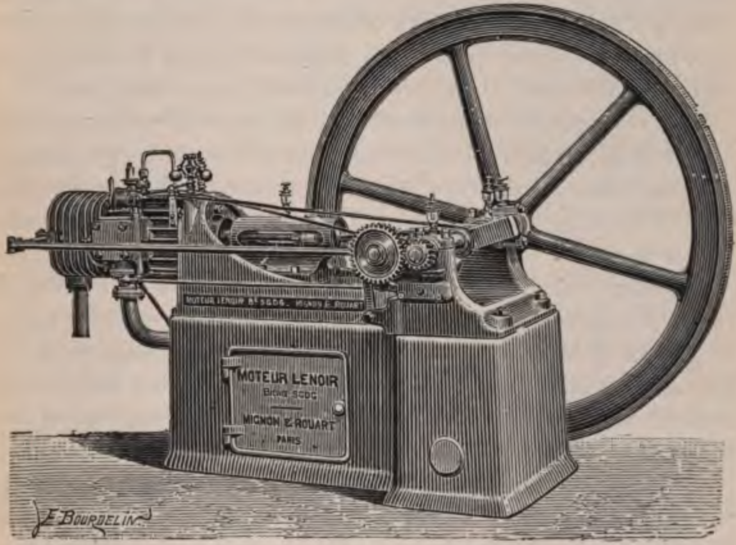


FIG. 229.—MODERN LENOIR ENGINE, 1883.

A simple *centrifugal ball governor* regulates the speed by raising a lever so that it misses the admission valve stem, and thus cuts off supply when the speed is too high.

These engines are made by MM. Rouart Frères et Cie., and the Compagnie Parisienne d'Eclairage au Gaz, in sizes up to 8 horse-power in one cylinder, and with two cylinders to 50 horse-power.

Trial.—In 1885 M. Tresca tested a modern Lenoir engine working with Paris gas. The most complete results were obtained in a run of two hours on May 9, 1885. The engine gave 1·93 horse-power (metric) on the brake at 176 revolutions per minute. Pressure of charge in hot cartridge before ignition was about 68 lb. per square inch (4·8 kilogs. per square centimetre), the explosion 230 lb. per square inch (16·1 kilogs. per square centimetre), and the mean effective pressure 146·5 lb. per square inch (10·3 kilogs. per square centimetre). The mechanical efficiency was 72 per cent., and the consumption of Paris gas (677 litres) 23·9 cubic feet per brake horse-power hour.

Bénier.—An interesting combination, used in France, is the Bénier gas engine and generator, which makes every charge of gas as it is drawn into the cylinder by the suction of the piston. Prof. Witz points out that MM. Bénier have found this the best method of using cheap fuel gas in engines of less than 30 horse-power.

Producer.—Anthracite or coke is fed by a hopper into the furnace. Steam is generated in the hollow circular grate of the gas producer, from a stream of water passing over the bars. There is an annular space in the fire-brick between the furnace lining and the outer casing. Here the steam is superheated on its way to the furnace, when drawn along with air, by the suction of the piston. The fuel gases pass from the top of the furnace, through a washer, direct to the engine. There is no gas-holder, scrubber or other purifier.

The *Engine* has two cylinders side by side, the motor and pump, with pistons connected to the main shaft. The pump crank is set at an angle of 90° in advance of the other. The pump is formed of two cylinders in tandem, fitted with a differential piston, which draws the gas from the generator and the atmospheric air by separate valves, and delivers them into a mixing chamber in the back cover of the motor cylinder. The admission port to the motor cylinder is partly blocked by small perforated discs, in order to mix the gas and air thoroughly. Air is passed in first to clear out the products of combustion through the exhaust ports, which are uncovered by the motor piston at five-sixths of its working stroke until closed again by the piston at one-sixth of its return compression stroke. During the remainder of the return stroke the charge is compressed in the motor cylinder. At the dead centre the charge is fired by the electric spark. There is thus an explosion every revolution.

The quantity of gas admitted to the pump is regulated by the governor, giving explosions of variable strength. The charge may thus become too poor to be inflammable, and so escape by the exhaust without being burned. There is also the danger of loss of gas by the exhaust with the scavenging air, which forms the first part of the charge.

The engine is *started* with coal gas where available. Otherwise a *starter* with gasoline is used. This consists of a small vessel containing gasoline, an air pump worked by hand, and a carburettor surrounded by a heating jacket filled with hot water to prevent too great a fall in temperature by the evaporation of the gasoline. In order to start, the motor piston is set at about one-third of its working stroke, a cock is opened to allow the gasoline to fall into the carburettor, and after a certain number of strokes of the air pump, communication is opened with the motor cylinder, and the charge fired therein by passing the electric spark. When the speed has got up, the suction pipe is opened to the gas producer, and each charge of gas is drawn directly therefrom during the suction stroke of the engine.

The Bénier gas engine and generator are made by the Société des Moteurs-Gazogènes Bénier of Paris, in sizes up to 50 horse-power.

Trials.—In 1894, Professor Witz tested a Bénier gazogène-motor plant. The engine was 15 horse-power, and the producer suitable for 25 horse-power with anthracite, and was large enough to make gas from coke for the 15 horse-power engine. The motor cylinder was 11·8 inches in diameter, and the stroke 17·3 inches. The diameter of the air pump was 15·75 inches, and that of the gas pump 11·4 inches, the stroke being 8·23 inches. In one trial English anthracite was used, and in the second, broken gas coke containing 6·5 per cent. water, and giving about 10 per cent. cinders. Fig. 230 is the mean indicator diagram obtained in the first trial.

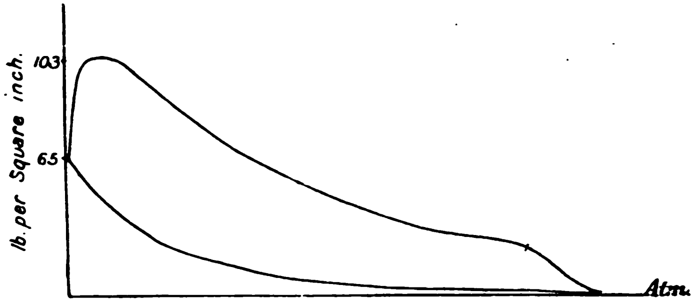


FIG. 230.—MEAN INDICATOR DIAGRAM. BÉNIER MOTOR.
Mean pressure 37·7 lb. per square inch.

RESULTS OF TRIALS OF BÉNIER GAZOGÈNE-MOTOR.

Date 1894	November 27	December 22
Duration of trial, hours . . .	12	10·4
Revolutions per minute, mean . .	151	147
Brake horse-power (French) . .	14·59	14·7
Indicated horse-power . . .	27·6	..
Power spent in pumps, &c. . .	13	..
Mechanical efficiency, per cent. .	53	..
Fuel used	Anthracite	gas coke
Per brake horse-power hour (metric)	1·5 lb.	1·65 lb.
Heating value in B.Th.U. per lb. .	14,400	12,240
,, ,, of gas B.Th U. per cubic foot at 0° C. and 760 mm. . .	128·7	116
Thermal efficiency of engine and generator combined	11·3	12·4
Cost of fuel per brake horse-power hour	0·25*d.*	0·21*d.*

A large fraction of the power developed in the cylinder is spent in friction of the pumps and mechanism.

Professor Witz concludes that an effective horse-power hour is easily obtained from 1·6 lb. (750 grammes) of anthracite, and the cost is only 0·4*d.* (4 centimes); whilst the best gas engines use per brake horse-power hour (500 litres) 17·65 cubic feet of town gas, which costs 12 centimes in France.

Koerting.—The vertical gas engine designed by KOERTING of Hanover dates from 1879, and is one of the oldest and most largely used engines in Germany.

The original Koerting-Lieckfeldt type of vertical engine had separate pump and motor cylinder giving an impulse every revolution. The pump always drew in the same volume and proportion of explosive mixture and compressed it into the motor cylinder at normal speed, but if the speed was too high the governor opened a valve between the pump and a reservoir into which part of the compressed mixture was forced, so that a variable charge was delivered into the motor cylinder. This construction of the engine, as described and tested by Schœttler, was abandoned.

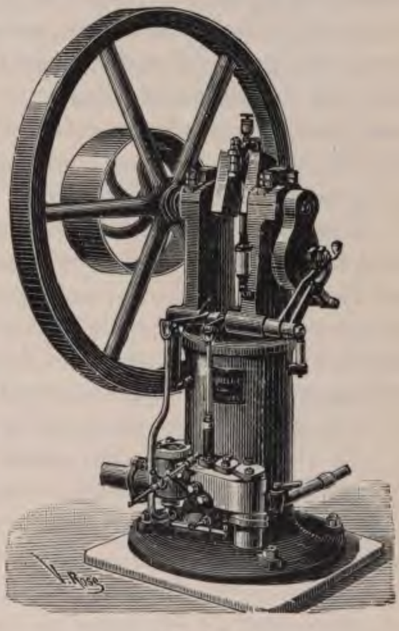


FIG. 231.
KOERTING GAS ENGINE.

In the 1888 type of Koerting engine the Beau de Rochas four-stroke cycle was adopted. The new vertical type, Fig. 231, is also made by Boule & Cie., of Paris, in sizes up to 10 effective horse-power. The valves are easily got at. The exhaust and ignition valves are worked by two levers on a rocking shaft, shown above the cylinder, actuated by cams. The cam shaft is driven at half speed of the crank-shaft by gear wheels at the side. Ignition is now by heated porcelain tube; but two novel features of the Koerting engine were (1) the method of ignition by propagation of flame in a conical tube, and (2) governing the speed by holding the exhaust valve open, now common in other engines. The charge is usually admitted through a valve which opens automatically by the suction of the piston. When the speed is too high the governor acts on a lever which keeps the exhaust valve open and closes a return valve. No fresh charge can enter, since there is no vacuum in the cylinder, and the piston simply draws into the cylinder and pumps out again the discharge products by the exhaust, instead of taking in a fresh charge, until the speed is reduced to the normal and the governor releases the exhaust valve.

The large gas engines are made horizontal, both single and double-acting on the four-stroke cycle, with one cylinder or two cylinders in tandem. In the latter, the piston and piston rod are made hollow and water-cooled. The cooling water for the piston circulates through sliding telescopic pipes moving to and fro with the cross-head working through guides. The stuffing box has metallic packing and is water-cooled.

In the 1900 type the motor cylinder is double-acting, having conical ends, each with one admission lift valve. Two double-acting pumps, driven from an auxiliary crank and having piston valves worked from an eccentric, deliver gas and air through separate pipes to each admission valve. At the end of an explosion stroke the motor piston, which is equal in length to the stroke, uncovers the exhaust ports round the middle of the cylinder, and the air pump delivers scavenging air, When the exhaust ports are closed by the piston, on its return, the charge of gas is admitted and compressed. At the dead point the charge is fired by electric sparks, and is expanded during the out stroke. There are thus two explosions per revolution—one on each side of the piston. The engine governs by varying the quantity of gas admitted. An engine with compression 12·5 atmospheres (absolute) and explosion pressure 27·5 atmospheres, gave

341·5 brake horse-power with gas of 129 B.Th.U. per cubic foot, at 58 cubic feet per indicated horse-power hour and 81·5 cubic feet per brake horse-power hour.

Capitaine.—The vertical high-speed engine, designed by HERR EMILE CAPITAINE in 1888, works on the Beau de Rochas cycle, and has a single-acting cylinder with a conical combustion chamber at the top and open below. The truncated piston is connected with a cross-head which slides in a guide and works the crank-shaft below. The piston makes short rapid strokes, maintaining the usual speed of piston, and giving double the usual number of explosions per minute, at 360 to 400 revolutions per minute. The cylinder is made large in diameter, so that the rate of expansion of the gases is doubled and the explosion is practically instantaneous. In constructing the engine the area of ports is proportioned to this speed for the gases, and the bearing surfaces are made broad, large, and well lubricated to reduce friction. The gain in economy by rapid explosion and expansion depends on the certainty of ignition and the rate of propagation of flame in the mixture. Capitaine also aims at stratification of the charge. The air and gas admitted through an automatic lift valve mix in an annular chamber which gives them a circular motion. The conical shape of the combustion chamber is also intended to check and steady the motion of the fresh charge, and keep it apart from the residual burnt gases which are supposed to remain next the piston during its suction or down stroke. However, diffusion must take place to some extent during compression in the up stroke. At the desired instant on the return of the piston the compressed charge is fired by the hot ignition tube without any timing valve. The exhaust valve spindle is operated by a bell-crank lever worked by a swinging arm and eccentric rod from the crank-shaft. The speed is regulated by the method employed by Koerting. When the speed is too high the centrifugal governor balls fly apart and move a sliding collar and bell-crank lever, and a detent holds it and keeps the exhaust valve open while the speed is above normal. The engine is built on the same lines as the Grob-Capitaine petroleum engine.

CHAPTER XI.

ELEMENTARY PRINCIPLES AND CALCULATIONS.

THE reader is not expected to rest satisfied when he becomes familiar merely with the mechanical details and working of several gas and petroleum engines. He will best obtain a real grasp and thoroughly useful knowledge of this subject by adopting the natural method of study—that is, *by making trials, actual experiments, and measurements for himself.* The practical man can readily measure the work done by an engine for a given consumption of fuel; and at the same time he may take indicator diagrams to find out what is going on in the cylinder. In order to obtain the best conditions of working, he will naturally inquire into all the sources of waste, and how it comes that one engine is more efficient than another. Again, in the laboratory, *quantitative experiments* should also be carried out on *heat* and *work*, including the conversion of heat energy into mechanical energy to do useful work. The nature and laws of gases will be investigated, and experiments made to determine the *amount of heat generated by burning different kinds of fuel.*

The next step will be to *make use of the results obtained* in this way. The student will seek to derive useful information from the indicator diagram, and to clearly understand the meaning and cause of all its peculiarities; in a word, to find what it reveals to him regarding the working of the engine and the behaviour of the gases in the cylinder. He should also be able to **make calculations** and *deduce practical conclusions from his own observations* on the performance of these heat engines.

In order to start with exact notions, we shall briefly consider some of the elementary principles and fundamental facts necessary for a clear conception of the theory and practical possibilities of the internal combustion engine.

Weights and Measures.—Throughout the United Kingdom the legal standard measure of **length** is the *Imperial standard* **yard**, declared by Act of Parliament * to be the distance between the centres of two gold plugs in the bronze bar deposited in the Standards Department of the Board of Trade in the custody of the Warden of the Standards, when the bar is at the temperature of 62° F. and supported on bronze rollers in such a manner as best to avoid flexure of the bar, and to facilitate its free expansion and contraction from variations of temperature. One-third part of the standard yard is a *foot*, and the twelfth part of the foot is one *inch*.

The unit of **time** is one mean solar **second**.

When any quantity varies with the time in such a manner that it undergoes equal changes in equal intervals of time, we say that it varies at a constant rate, and we define its *rate of change* as the change which it undergoes in unit time.

Velocity is rate of change of position, or rate of motion. Thus, if we say that the velocity of a certain body moving at a constant rate is 10 feet per second, we mean that the body moves through a distance of 10 feet in every second. When the velocity is changing, we can only measure the *average velocity* even during a short interval of time. If a fly-wheel 18 feet in circumference makes 200 revolutions per minute, any point on the rim moves through 18 × 200, or 3600 feet in 60 seconds, and the *average velocity* or rim speed during this time is 60 feet per second.

Acceleration is the time rate of change of velocity, and is measured in *feet per second per second.* When we say that the acceleration of a body is 2 feet per second per second, we mean that its velocity undergoes a change of 2 feet per second in every second. A body falling freely in Great Britain has a uniform acceleration g of about 32·2 feet per second per second.

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* 41 and 42 Vict. c. 49.

One of the most characteristic properties of matter is its **inertia.** By this term we mean the tendency of every body to continue in its state as regards rest or motion. Thus, a body originally at rest will tend to remain at rest for ever, and a body originally moving with a given speed in a given direction will tend to move with the same *speed and in the same direction.*

The objects which come under our observation are, as a rule, undergoing continual change of motion. But, as we have just seen, a body left to itself will tend to maintain its state of motion. We agree to say that the changes in the motions of bodies are due to the action of certain causes which we term *forces.* By a force, then, we simply mean any cause which alters a body's state as regards rest or motion.

The **mass** of a body is the quantity of matter or stuff in it, which we measure by **weight.** One of the effects of a force when applied to a definite mass, is to accelerate its motion; and *the measure of the force is taken as the mass multiplied by the rate of change of velocity,*

$$\textit{force} = \textit{mass} \times \textit{acceleration}.$$

Experiment shows that when a body, originally at rest, is allowed to fall freely, only acted on by its own weight—that is, the attraction or downward pull of the earth on the mass of the body—its velocity at the end of the first second varies with the latitude and distance above the sea level, and is about 32·2 feet per second for Great Britain. The gravitational force or weight W of a body will vary accordingly, since it is equal to the mass m of the body multiplied by the acceleration g.

The quantity W/g for a body anywhere is constant, and called the mass m of the body.

The British engineer's unit of **force** is the *pound weight,* the Imperial standard **pound** (**1 lb.**) avoirdupois of 16 ounces or 7000 grains. Any body whose weight is W pounds in Great Britain, has a mass $W \div 32 \cdot 2$.

Two bodies of equal weight at any place have equal masses, that is, contain equal quantities of matter or stuff which remain the same when the substance undergoes chemical transformation.

The legal standard measure of **weight** is the *Imperial standard* **pound**, declared to be the weight in vacuo of the platinum weight, in the form of a cylinder nearly 1·35 inch in height and 1·15 inch in diameter, with a groove or channel round it near the top, and marked P. S. 1844, 1 lb., also kept in the Standards Department. Every measure and weight used for trade shall be verified and stamped by an inspector. Once every five years local standards of weight and measure are verified by comparison with the Board of Trade brass secondary standards, and the latter compared with accurate parliamentary copies of the Imperial standards.

The unit or standard measure of **capacity** is the British * legal Imperial standard **gallon**, containing ten pounds weight (**10 lb.**) of distilled water, weighed in air against brass weights at the standard temperature of 62° F., and with the barometer at 30 inches. One-fourth part of the gallon is the *quart*, and the *pint* is one-eighth part of the gallon.

The **Imperial gallon** of **8 pints** was 277·274 cubic inches, or by recent measurement 277·463 cubic inches. In Great Britain *a pint of pure water weighs a pound and a quarter*. A **cubic foot** of **pure water** weighed in the air at 62° F., the barometer being at 30 inches, is equal to **62·3 lb.**

The **specific gravity** of a substance is its weight at 60° F., as compared with the weight of the same bulk of water. The **density** or *weight per unit volume* of pure water at its temperature of maximum density, 39° F. (4° C.), being taken as unity, the specific gravity of mercury is 13·596 at 32° F. (0° C.).

A cubic foot of pure water in vacuo at 39° F. weighs 62·425 lb.; and a cubic foot of air at ordinary pressure weighs 0·0807 lb. at 32° F., or 0·076 lb. at 62° F.

In the **metric system** the standard of length is the **metre**, which is the length of a certain bar of platinum at 0° C. The hundredth part of this, called a *centimetre*, is the unit of length in the centimetre-gramme-second system universally adopted for scientific measurements. One centimetre is equal to 0·3937 inch, or 1 inch = 2·54 centimetres, and 1 foot = 0·3048 metre.

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* See *Weights and Measures Acts* of 1878, 1889, 1892 and 1893; and *Our Weights and Measures*, by H. J. Chaney.

1 metre = 100 centimetres = 1000 millimetres = 39·37 inches.

1 litre = 1000 cubic centimetres = 0·22 gallon.

1 cubic metre = 1000 litres = **35·32 cubic feet,**

or 1 cubic foot = 0·02832 cubic metre.

In the C.G.S. system* a **gramme** represents the mass of a cubic centimetre of pure water at 4° C., thus

1 lb. = 453·59 grammes.

1 *litre of pure water weighs* 1 *kilogramme.*

One kilogramme (kilo.) is 1000 grammes **or 2·2 lb.**

In the metric system, the engineer's unit of mass is the International standard **kilogramme**, a solid piece of iridio-platinum in the form of a cylinder, the height equal to the diameter of 39 millimetres at 0° C.

The C.G.S. unit of force is a **dyne**, or *that force which, acting on a gramme for a second, generates a velocity of a centimetre per second;* that is, gives to it unit acceleration.

A gramme's weight is about 981 dynes.

A force is always distributed over some area, however small, and *the force exerted upon a unit area of surface is called the* **Pressure.** 1 lb. per square inch = 0·0703 kilogramme per square centimetre; or 14·223 lb. per square inch = 1 kilo. per square cm.

We shall take the normal **atmospheric pressure** as

14·7 *lb. per square inch* = 1·0333 *kilo. per square cm.*

The *atmospheric pressure* is given by the height of the barometer, and for comparison, should be corrected to sea level at latitude 45°, and at 0° C. or 32° F., the temperature of melting ice.

The normal or *standard pressure* is that of 760 millimetres = 29·92 inches of ice-cold mercury at latitude 45°, or 29·9 inches (nearly 30 inches) in London.

Absolute pressure is measured from a vacuum, and is equal to the sum of the gauge or indicator pressure and the atmospheric pressure obtained from the barometer reading.

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* Professor Everett's *C.G.S. System of Units.*

A *water gauge manometer* is employed to measure the slight variation in pressure of gas supply above or below atmospheric pressure. The common form consists of a U-shaped glass tube half filled with water, having one end open to the atmosphere and the other in communication with the gas. The difference in the height of the columns is measured in inches on a scale placed between them.

One inch of water is equal to a pressure of 0·036 lb. per square inch, and each foot of "*head*" of water = 0·433 lb. per square inch.

The Bourdon gauge is used to measure and record the pressure of water and steam.

Gauges and indicator springs for measuring pressures are tested by comparison with a mercury column subjected to steam pressure. Increase the steam pressure by steps, and check by readings at the same points with rising and falling pressures. Errors due to heating of the indicator and friction may thus be corrected, and the true scale of the spring obtained.

WORK.

Work is done when a force is exerted through any distance in its own direction. *The measure of a force in pounds, multiplied by the distance in feet through which it acts, gives the work done by the force in foot-pounds.* The **unit of work** usually employed by British engineers is the work done by gravity on the mass of one pound in falling through a height of one foot, and is called **one foot-pound.** It is the amount of work necessary to raise a **pound weight** *through the height of* **one foot**, that is, to overcome the mutual attraction between 1 lb. and the Earth through a distance of one foot.

If we raise 14 lb. a height of 5 feet against gravity, we do 14 × 5, or 70 foot-pounds of work, whilst this mass in falling through the same difference of level is capable of doing the same amount of work. In lifting a mass vertically we overcome the mutual attraction between that mass and the Earth, and do work; but in moving a mass in a horizontal direction there is no work done against gravity, we merely overcome the resistance of friction, and the work done is always found by multiplying the resistance by the distance through which it is overcome.

In a gas engine cylinder the pressure of gas on the piston does no work until it moves the piston. If by heating the gas we keep its pressure constantly 60 lb. per square inch whilst it expands, driving the piston through a distance of 2 feet; the piston exposed to the pressure having diameter 6 inches, how much work is done by the gas?

Answer:—The area of piston exposed to pressure is $0{\cdot}7854 \times 6 \times 6$ square inches; there is, therefore, a total pressure of $0{\cdot}7854 \times 6 \times 6 \times 60$ lb. on the piston, driving it through a distance of 2 feet.

Hence the work done by the gas on the piston is

$$\text{force (lb.)} \times \text{distance (ft.)} = 0{\cdot}7854 \times 6 \times 6 \times 60 \times 2,$$

that is, 3392·9 foot-lbs.

In general, if a square inches be the effective area of a piston exposed to a constant gaseous pressure of p lb. per square inch, or a total force of $p\ a$ lb., which drives it through l feet length in the cylinder, then the amount of work done by the gas on the piston is $p\ a\ l$ foot-lb., and is independent of the time in which it is performed.

The C.G.S. unit of work is an *erg*, which is the amount of work done by a *dyne* in working through a distance of a centimetre. The gramme-centimetre, another unit of work, is the work done in raising a mass of one gramme against gravity through one centimetre, and is equal to 981 ergs. The unit of work in the metric system is the *kilogram-metre*, that is, the work done in raising a kilo. against gravity through a height of 1 metre. A convenient *practical* unit of work employed by electrical engineers is

1 joule = 10,000,000 ergs = **0·7372 foot-lb.**, and
1 foot-lb. = 0·13825 kilogram-metre = $1{\cdot}3562 \times 10^7$ ergs.
7·233 foot-lbs. = 1 kilogram-metre.

Work can be represented graphically by an area.

This is obvious in the case when the pressure is constant throughout the travel of the piston.

Take a height O P, Fig. 232, to represent the total pressure or force *p a pounds*, to some suitable scale, and at right angles to it draw O L to represent the length l in *feet* travelled by a piston under this constant pressure, then the rectangular area O P A L represents the work done $p a l$ in *foot-pounds*, since it is found by multiplying the value of O P by that of O L.

To prove that this holds true when the pressure is variable. Let distances measured from O along O p or heights above O v represent pressures in pounds per square inch, and distances along O v represent lengths of cylinder swept out by the piston.

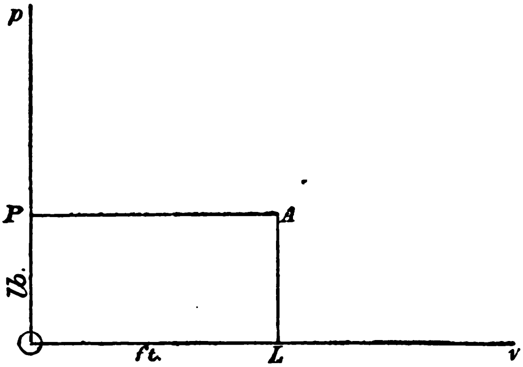

FIG. 232.

Suppose a mixture of gas and air enclosed in the cylinder, Fig. 233, its volume is given by the length O L of cylinder occupied, since it is equal to O L multiplied by the sectional area of cylinder, whilst its pressure of p lb. per square inch is shown by the height L P. Thus the *point* P *represents the condition of the mixture as regards pressure and volume* by the height above O v and distance from O p. It is evident that if either of these vary, the point P will change its position accordingly to indicate the corresponding pressure and volume, and the *curve traced out by the point* P will, moreover, be *a graphic representation of the law connecting the pressure and* *volume of the substance in the cylinder,* since it shows how the one varies with the other.

As the mixture of gas and air burns and expands, forcing the piston along the cylinder from L to L′, the pressure falls to L′ P′ or p' lb. per square inch, as indicated by the curve P P′. If the area of the piston exposed to pressure be a square inches, then the total effective pressure at L is $p\ a$ lb., and at L′ it has become $p'\ a$ lb. Divide the line L L′ into any number of equal parts, and construct the little rectangles as in Fig. 233.

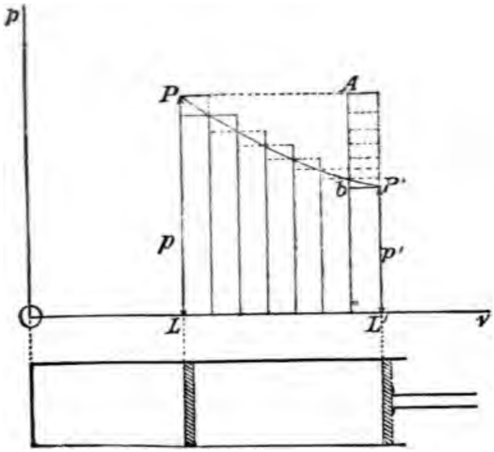

FIG. 233.

Now conceive the pressure instead of falling gradually, as it really does, to remain constant during each short interval or motion of piston, and to fall suddenly by steps; then the area of each rectangular strip would represent the work done, on every square inch of piston, by the gas during that part of the piston's motion, being equal to the average height or pressure multiplied by the distance this has moved the piston. In this way the sum of all the elementary rectangles would represent the total work done per square inch of piston, those above the curve being too great, and the others below it too small.

By dividing the distance, L L′, travelled by piston into a very great number of equal parts, and constructing rectangles on them, the heights will change less suddenly and approximate more closely to the real pressures; and when we imagine an indefinitely great number of equal parts in the line L L′, the pressures will fall gradually along the curve P P′. Now, by projecting across, as in Fig. 233, we see that the difference rea between the sum of all the longer rectangles extending above the curve, and the parts of them below it, is equal to the rectangle P′ A, having height equal to the difference of the pressures at P and P′ whilst its base P′ *b* can be made as small as we please by increasing the number of parts in L L′. The rectangle P′ A can thus be made smaller than any finite quantity. Hence in the limit, when L L′ is divided into an indefinitely great number of equal parts, the sum of all the rectangles below the curve becomes equal to the area of all those reaching above it; or, in other words, the sum of all the elementary rectangles equals the area L P P′ L′. Therefore *this area* LPP′ L, *bounded by the curve* P P′, *represents exactly the work done on the piston by the burning gas in expanding from* L *to* L′.

It follows that the work done by a gas can be calculated when the law of its expansion is known.

If the sectional area a be expressed in square feet, then $a\,l$ cubic feet is the small **change in volume** (dv say) of the gas, whilst the **pressure** p lb. per square foot remains constant; therefore the element of work done (dw), in that short interval, is $p\,a\,l$ equal to $p \times dv$. This may be represented by the area of one little strip, Fig. 233. Adding together all the little strips between the two limits of volume v_1 and v_2, that is, adding up all the values of $p \times dv$ between these limits, we get

$$\int_{v_1}^{v_2} p\,dv = \int_{v_1}^{v_2} dw = \text{W},$$

where W stands for the work done by the gas in expanding from volume v_1 to volume v_2.

Suppose the law, $\frac{p\,v}{\text{T}} = \text{R}$, that is, $p = \frac{\text{R T}}{v}$, holds for the gas during the expansion; then we have

$$\text{Work done} = \int_{v_1}^{v_2} p\,dv = \int_{v_1}^{v_2} \frac{\text{R T}}{v}\,dv = \text{R T} \int_{v_1}^{v_2} \frac{dv}{v},$$

and

$$\text{W} = \text{R T} \log_\epsilon \frac{v_2}{v_1} = p\,v \log_\epsilon \frac{v_2}{v_1}.$$

Multiply common logarithms (to the base 10) by 2·3026 to convert them into Napierian logarithms (to the base ϵ = 2·71828) used in this formula.

THE INDICATOR.

The **Indicator** invented by JAMES WATT enables us, by this graphic method, to trace and record all the alterations in pressure of the working substance in the cylinder, to detect faulty setting of valves and irregularities in the action of an engine, and to calculate the work done by the gas on the piston.

The original object of the indicator was merely to register the pressure in the cylinder of a steam engine at every point throughout the piston's stroke. This instrument, however, revealed to Watt much more about the working of his engines. From its diagram of what was going on in the cylinder and the behaviour of the steam therein, he could see at a glance whether the valves, steam ports and piston were working properly, and he was enabled to improve them accordingly.

Watt's indicator consists of a small cylinder connected by a pipe to the end of the engine cylinder so that the steam has free access to it. A closely-fitting piston works in this little cylinder with a piston rod, carrying a pencil directly attached at its upper end clear of the cylinder. The piston is pressed down by a spiral spring, and the steam pressure from the engine cylinder acting on its lower side overcomes the atmospheric pressure on its upper side, compresses the spring, and forces the piston with piston rod and pencil upward. The amount of compression or extension of the spring through a given range is proportional to the force applied, and each spring is tested before being used in the indicator, so that the pressure in the cylinder above or below that of the atmosphere is shown by the rise or fall of the pencil fixed on the piston rod. If the pressure underneath be equal to that of the atmosphere, the piston does not move. If it be greater, the piston is driven upwards and the spring compressed, but when the pressure is less than atmospheric the elasticity of the spring pushes the piston down. The pencil traces a line on a piece of paper which is moved to and fro in exactly the same time as the engine piston, only through a shorter range. A horizontal line will be traced when the pressure in the engine cylinder remains constant, and a gradual rise or fall in the pressure will be indicated by a curved line.

A *sudden* change of pressure would give a *vertical* line followed by vibrations of the spring, kept up by the inertia of the indicator piston and moving parts, which would carry the pencil beyond the true position for that pressure, and cause it to trace a wavy line, not a true indication of that pressure.

Higher pressures and quick speeds of piston increased this difficulty and necessitated improvements in the indicator. **McNaught** wrapped the sheet of paper on a hollow cylinder which was rotated about a vertical axis in one direction by a cord attached by reducing gear to the piston, and brought back by a flat spring coiled inside the drum.

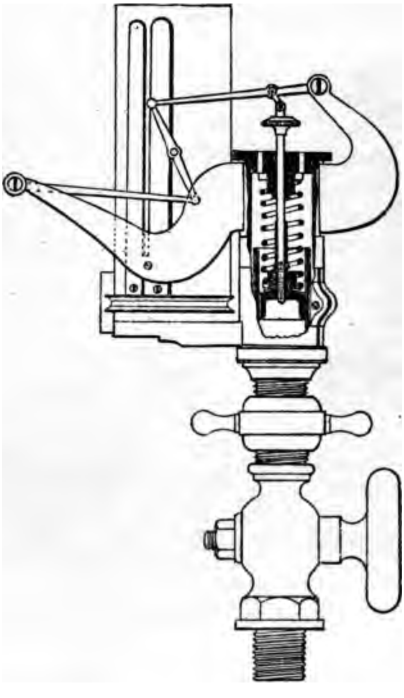

FIG. 234.—RICHARDS INDICATOR.

The **Richards Indicator**, designed about 1860 by Prof. Charles B. Richards, marks a great advance by the use of *light piston and moving parts*, with a *short, stiff spring*, allowing the indicator piston only a *short range of motion and magnifying this* by the linkage, consisting of two levers equal in length and connected by a link, like Watt's parallel motion, so that the tracing point at the middle of the link moves in a straight line.

One form of this indicator is given in Fig. 234, with the light piston and spiral spring in section.

The lower part is screwed into a hole drilled in the engine cylinder near its end, and over the clearance space untraversed by the piston. Sometimes the two ends of a steam engine cylinder are connected by a pipe with a three-way cock, to which the indicator may be attached. The indications of the steam pressure at both ends of the cylinder can be obtained in rapid succession by simply turning this cock one way or the other. However, long narrow pipes must not be used between the cylinder and indicator; on the contrary, the passages must be wide and short, so as not to throttle the steam and thereby reduce the pressure.

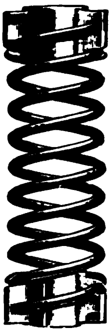

FIG. 235.
TABOR INDICATOR SPRING.

The little cylinder of the indicator, Fig. 234, contains a true and easy fitting piston, the space below which must be in perfectly free communication with the engine cylinder when the stop-cock is open. In the upper part of this cylinder there is a short spiral spring, shown detached in Fig. 235, one end of which is attached to the little piston and the other end is screwed into the top cover. The latter is always open at the top to the atmosphere. When the indicator cock is opened the piston is exposed to the same gaseous pressure as the piston in the engine cylinder, and is urged upwards against the spiral spring. The compression or extension of this spring is proportional to the pressure above or below that of the atmosphere, as in Watt's indicator.

The motion of the indicator piston is magnified and registered by a pencil moved from the piston rod by the linkage. The piston rod is attached to one arm at one-fourth its length from the fulcrum. Hence any movement of the piston is magnified four times at the end of the lever, or by the pencil. The stout curved arm carrying the parallel motion turns freely around the cylinder on a collar, to allow the to mark the paper on the drum when desired. The pencil is generally made of metal, and marks a piece of specially prepared metallic paper, called an *indicator card*, which is fixed on the drum. To avoid the friction of the metal point some engineers use a hard lead pencil and glazed paper.

The cord in the groove round the bottom of the drum can be attached to some part having the same reciprocating motion as the engine piston, only within a shorter range. A simple piece of **reducing gear** for high speeds is a long rod swinging on a pin fixed at the top of a standard, and connected below by a short link to the piston, as in Fig. 236. The whole should be made in wood and very light to reduce inertia. A screw may be fixed in the long rod near the top to give the proper travel, or a segment fastened to it, as in Fig. 236, for the cord which joins it to the paper drum to obtain an accurate reduction of the piston's motion. This cord is selected of the most suitable quality, strong, but not stiff or heavy. Sometimes thin steel wire is used, so as not to be stretched by the varying pull of

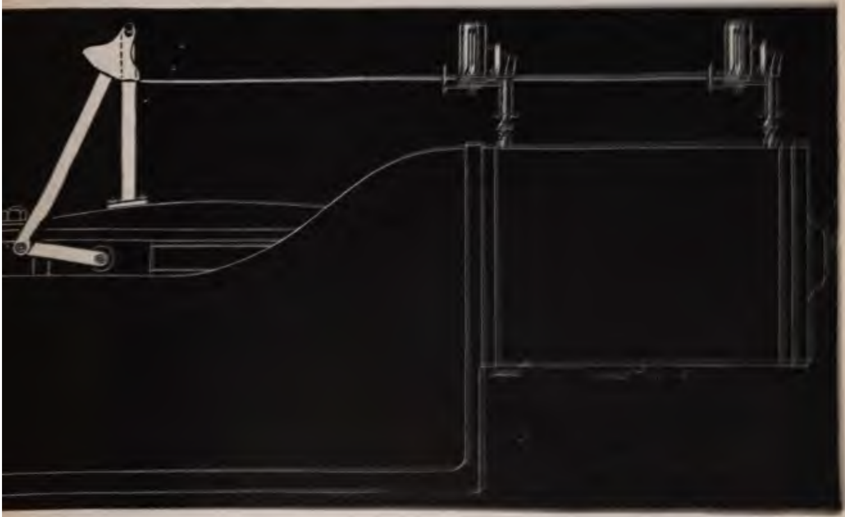

FIG. 236.—REDUCING GEAR AND INDICATORS.

the spring or reducing gear. The cord pulls the paper drum and makes it rotate in opposition to the drum spring, which always keeps the cord tight and brings back the drum to its original position.

The drum can be stopped or started at any time by a light hook and loop on the cord.

It is of the greatest importance to make the *paper drum move to and fro freely under the pencil in exactly the same time and way as the piston travels backward and forward in the engine cylinder.* The length of cord is adjusted to give a sufficiently wide range of motion to the drum, which must not be allowed to knock against the stops, else the whole travel of the piston will not be indicated.

In order that the pencil may indicate with delicacy *slight variations* in pressure, simultaneously as they occur in the engine cylinder, that is to make the instrument at once **sensitive and dead beat**, it is necessary to have a comparatively short, stiff spring, a light indicator piston, and very light moving parts attached thereto, and giving *minimum friction* at the rubbing surfaces.

Indicator springs of different strengths are marked with the number of pounds per square inch which makes the pencil rise one inch, and should be selected according to the pressures to be measured. Their indications give the pressure in pounds per square inch as measured by a scale supplied with each spring. The spring ought to be frequently calibrated in the indicator by comparison with a mercury column under steam pressure, because springs yield more when hot than cold. When a spring is disturbed by pressure suddenly applied, as from an explosion in the gas engine, it vibrates, causing the pencil to jump up and down, thus tracing a wavy line instead of a regular curve. This jerky, unsteady motion is very inconvenient. Mr. Richards partly overcomes the difficulty by employing short, stiff springs and magnifying their motion.

When the wavy curve is regular, as in the expansion part of an indicator diagram, the correct curve of pressure may be drawn by hand midway between the crests and hollows of the waves.

For high speeds, and rapidly varying pressures, the link motion gets up momentum and is violently shaken, damaging loose joints, causing back-lash, and giving inaccurate indications of the real pressure in the cylinder.

Thus an indicator, well adapted to the ordinary steam engine, may be quite unfit for use on the gas-engine cylinder, and may soon be broken if subjected to the sudden pressure of an explosion acting like a sharp blow. The pencil arm is liable to get bent or broken. In fact the Richards indicator is not well suited for gas-engine work, which severely tests the very best indicators. However, when modified by strengthening the parts, making the top cover or spring plate with a stop to come against the spring, it is sometimes used on the gas engine with satisfactory results.

The Author has used, amongst others, all the indicators here described on both gas and petroleum engines. It is of the utmost importance to keep these delicate instruments as cool as possible, to avoid overheating, sticking and friction of the piston, and for comfort in handling.

It is found that there are **five principal sources of error in indicators** which affect the diagram :—

1. The *inertia of the piston and parallel motion mechanism* attached thereto. The effect of this is to increase the size of the diagram and alter its shape. The obvious remedy is to *reduce the weight* of the piston, piston rod, and other moving parts, as far as strength and stiffness will allow. Back-lash, owing to looseness of the joints in the linkage, and on the other hand undue stiffness and friction, must be avoided.

2. The *inaccuracy of the indicator springs.*—Ordinary spiral springs give different results, depending on *how* the load is applied; hence they ought to be tested, and rated in the indicator *under the same conditions as in practice*, both as regards *temperature* and the *application* of the pressure.

3. The *friction* of the pencil on the paper keeps the pencil behind its true position, hence the necessity for *careful manipulation.* A graphite or hard lead pencil may be used, and a stop with screw adjustment provided to prevent the pencil being unduly pressed against the paper. The paper drum,

spindle piston and every joint should be kept properly lubricated with special oil to reduce friction and ensure perfect freedom of action, with no possibility of *sticking* when heated by the working fluid.

4. The *unequal stretching* of the indicator cord, due to the varying tension in it necessary to overcome the friction and inertia of the paper drum, as well as to the resistance of the drum spring during the forward and backward travel of the engine piston. Consequently the diagram will be still further distorted, and the mean indicated pressure diminished. Sometimes thin steel wire is used inside the cord with a view to get rid of this source of error. A new one should be well stretched before being applied to the indicator.

5. Deposit from burned or charred oil exposed to the flames in the engine cylinder tends to make the indicator plunger stick, and in the case of a badly working oil engine may choke up the passage to the indicator cylinder. No bends or small pipes should come between the indicator and engine to throttle the gas and reduce the pressure.

Thompson Indicator.—The next indicator suitable for use on gas engines, both in order of time and perfection, is that introduced by Mr. J. W. THOMPSON, and seen in half sectional elevation, Fig. 237, as made by Messrs. Schäffer and Budenberg. The chief features are (1) the link motion, and (2) the two sizes of pistons.

The link connecting the pencil arm to the piston rod has a ball and socket joint at the lower end to allow free motion. A movable collar around the upper part of the cylinder swings round against a stop to prevent undue pressure of the pencil on the paper. This collar carries a fixed standard with radius bar, as well as a link with the fulcrum of pencil arm at its upper end ; the lengths of these levers are so proportioned as to give the pencil an approximate straight line motion. The parts which move with a high velocity are made as light as possible consistent with strength and stiffness, in order to reduce their inertia to a minimum. This calls for the greatest nicety of workmanship.

The *paper drum* is shown separately in section, Fig. 237.

By removing the outer cylinder, loosening the nut on the top of the drum spindle, and by turning the disk holding the flat spring inside, the latter may be readily adjusted to suit any speed of engine up to 450 or 500 strokes per minute.

(2) For high explosion pressures a small piston, half the diameter of the other, is used in the indicator cylinder, thus reducing the blow on the linkage, and the same spring will measure four times the pressure, or the height of the indicator diagram will be reduced in this proportion.

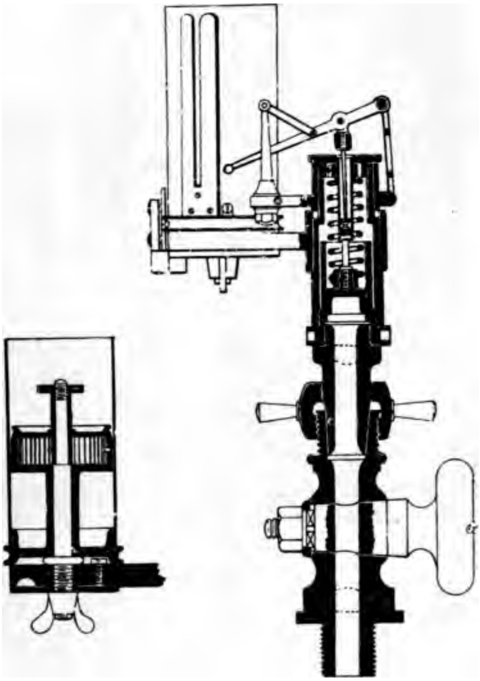

FIG. 237.—THOMPSON INDICATOR.

The small Thompson indicator stands the shocks of the explosions in gas engines and is easily handled.

Tabor.—The chief feature of the **Tabor Indicator**, Fig. 238, is the means of giving a straight line motion to the pencil point. The pencil bar carries a little roller which moves to and fro in the curved groove, so shaped in an upright plate as to compensate the tendency of the back link to move the pencil bar in a circular arc, and the pencil point moves up and down

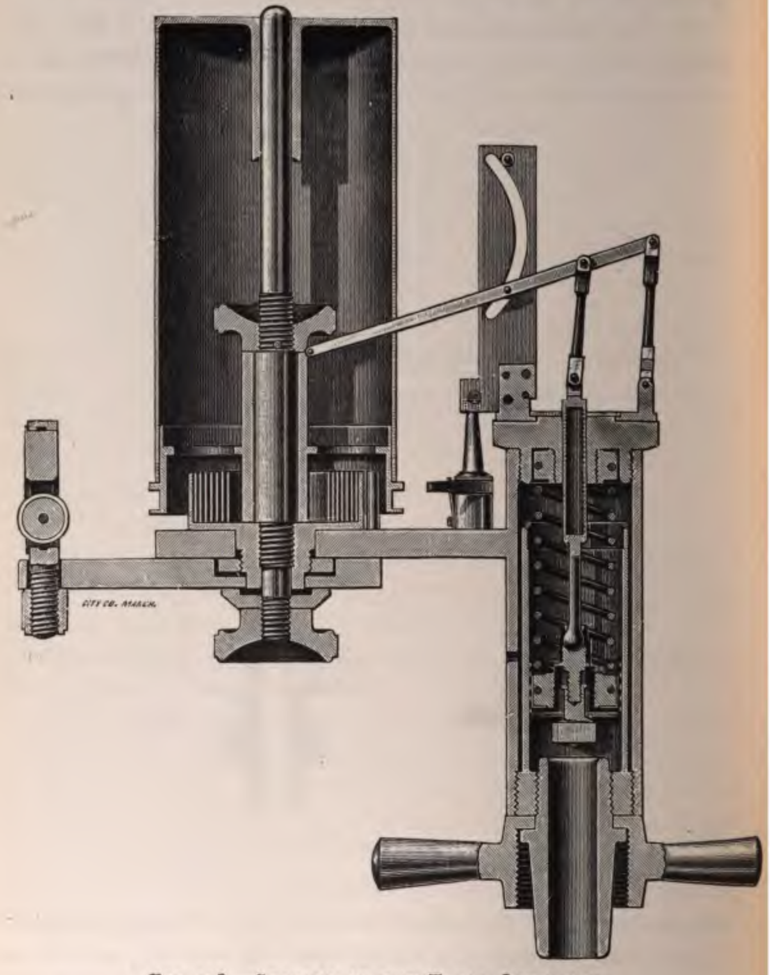

FIG. 238.—SECTION OF THE TABOR INDICATOR.

in a vertical straight line exactly five times as fast as the piston at every part of its range.

The piston rod is connected to the piston by a ball-and-socket joint, and the cylinder has a double wall. The spring Fig. 235, is made up of two coils of wire. The instrument is made larger than is usual in indicators best adapted for gas and petroleum engines.

Darke.—Darke's high-speed indicator is a neat little instrument, Fig. 240, made by Messrs. Elliott, and suitable for gas-engine indications. It is specially designed for high speeds and has light moving parts.

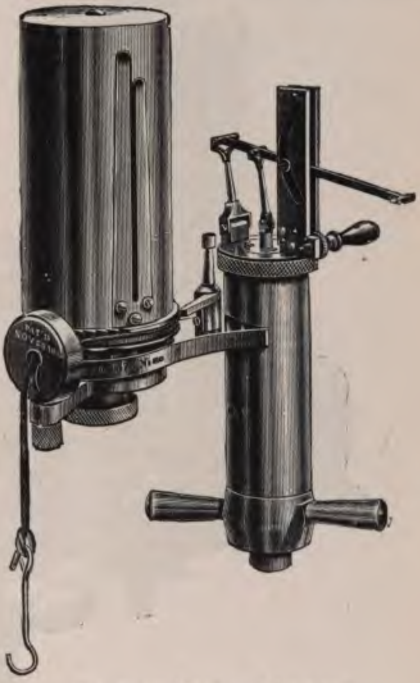

FIG 239.—TABOR INDICATOR.

The piston rod is made hollow and the springs short. Instead of the old heavy linkage, the pencil arm is a single lever pivoted by centre points on the two ends of a T-shaped head, and connected to a jaw on the piston rod head by a sleeve free to slide through a short range. The centre of gravity of the lever and pencil cross-head is almost directly over the piston rod centre. The free end of the lever carries a loose sliding piece, with a holder for the metallic pencil. The movement of the pencil is four times that of the piston. The pencil is kept in a vertical straight line by a slot guide in a plate, which is fixed to the collar on the cylinder top, and is moved round along with a pencil arm by a handle, to make the pencil touch the paper on the drum when a diagram is to be taken. The drum is made to hold a continuous roll of diagram paper, which comes out by a slit and is wrapped round the drum and held by a clip. Each diagram, when taken, is torn off, and part of the paper roll pulled out and fixed round the drum as before. The drum can be stopped while the engine is running, without disconnecting the cord, by means of *Darke's patent detent.* This consists of a tooth or pawl, which gears into the teeth of the ratchet segment at the lower part of the paper drum, and stops it by the action of the flat spring attached to the cylinder when the little knob is moved in one direction. When the knob is moved in the opposite direction the drum is released by this flat spring throwing the

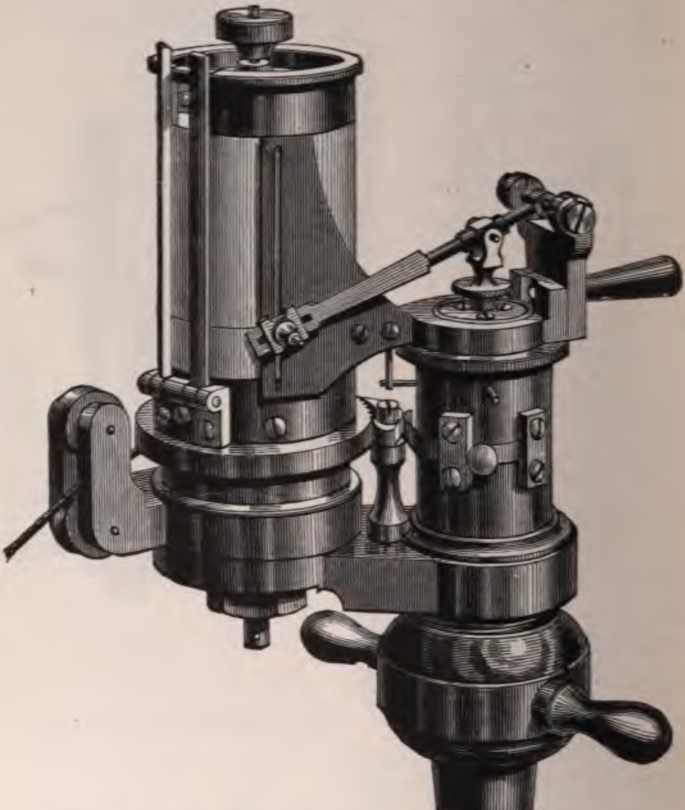

FIG. 240.—DARKE INDICATOR (¾ FULL SIZE).

pawl out of gear with the ratchet teeth. This arrangement is very convenient when several diagrams are to be taken in rapid succession from an engine running at high speed.

Crosby.—The Crosby Indicator, shown in Fig. 241, is one of the best fitted for use on gas engines.

It has a very light piston, parallel motion and drum.

The spring, Fig. 242, is made of one piece of steel wire, wound from the middle into a double spiral.

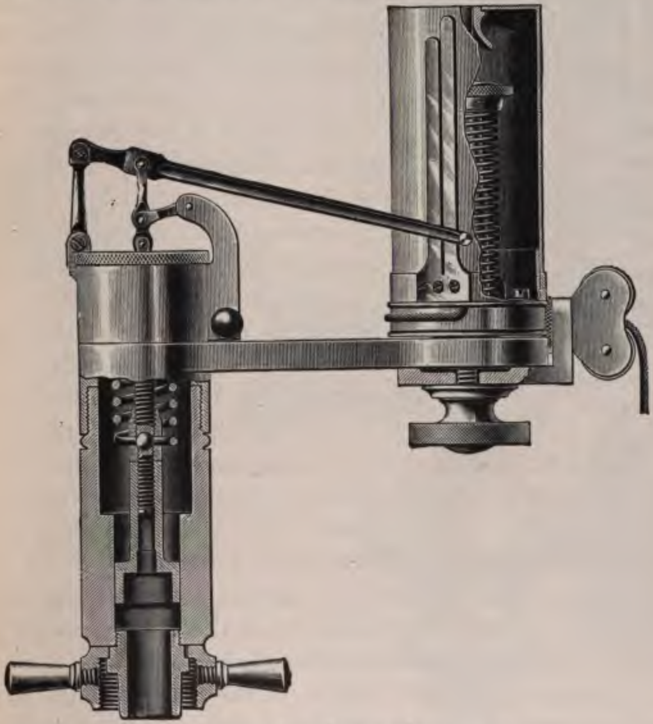

FIG. 241.—THE CROSBY INDICATOR.

On the middle of the spring is brazed a small steel ball which fits a socket in the hollow piston rod, and is adjusted to the proper tightness by the screw below, so as to allow free motion and prevent sticking.

Besides having the bearing in the centre of the piston by the ball-and-socket joint, there is the further material advantage of reduction in weight at the lower end of the spring, where it is most needed, because this part has the same motion as the piston, and therefore would otherwise have great inertia.

The cylinder is made of two bores, the lower one being half the area of the upper, to take a small piston for the high pressures suddenly developed by explosions. The same spring can thus be used for twice the pressure.

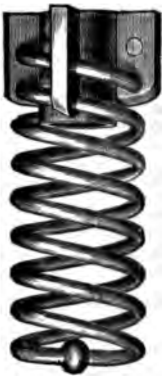

FIG. 242.—CROSBY SPRING.

The springs are rated in the indicator by the pressure of dry hot steam. Use a spring so that the diagram will only be one inch and three-quarters high: thus when measuring high pressures up to 350 lb. per square inch, use a stiff piston spring number 100, or $\frac{1}{100}$, with the small piston to reduce the force of the blow, and the height of the diagram will be only half that obtained with the same spring on the piston of double area, namely 1·75 inch for 350 lb. pressure.

The very slight movement of the indicator spring is then magnified to 6 times the range by the pencil. The long pencil arm, necessary for this multiplication, is the weak part of the instrument. For gas-engine purposes the pencil arm is made of L-shaped section steel tapering towards the point carrying the pencil, so as to have its centre of gravity directly over the piston rod centre, and especially to be stiff and strong enough to withstand sudden and frequent blows delivered on the indicator piston from the explosions in the cylinder of the internal combustion engine.

In careless hands the friction of the pencil on the paper sometimes tears the paper when it is pressed too hard. This is prevented by a stop for the sleeve on the cylinder, Fig. 241, carrying the link motion. A screw comes against the stop and can be adjusted to a nicety, so that the pencil point is allowed just to touch the paper and make a visible mark.

The paper drum has a *spiral spring*, which can be tightened and adjusted by the collar and lock-nut at the top to suit the speed of the engine to be indicated. This spring offers increasing resistance as it is compressed by the rotation of the drum, overcomes the inertia and friction of the drum, and thus maintains a constant tension in the cord connected by the reducing gear to the engine piston.

At the bottom of the paper drum there is a swivel guide pulley, which can be turned and clamped in such a position that the cord runs straight and directly from the drum to the reducing gear.

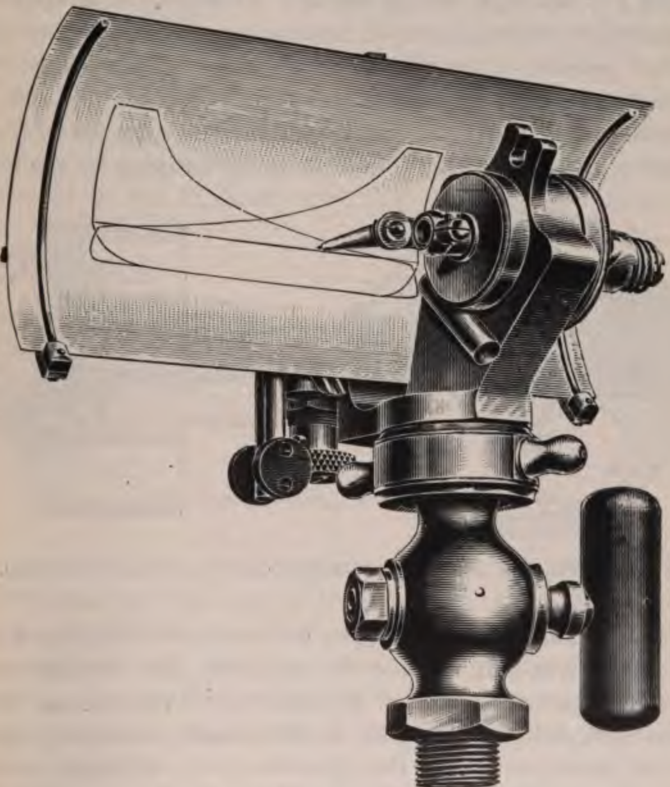

FIG. 243.—THE WAYNE INDICATOR.

A safety stop is provided for the piston rod to prevent undue compression of the spring, and protect the mechanism from injury by violent explosions or when the spring is not stiff enough; also when taking pumping diagrams with a light spring.

When used in a careful manner the Crosby indicator gives reliable diagrams. In common with other indicators, it is found that the pins in the link motion are apt to wear loose.

Wayne.—The Wayne Indicator, Fig. 243, has a rotary instead of the usual reciprocating plunger piston. In the cross-sectional end view, Fig. 244, C C is the cylinder in which the piston P P mounted on the spindle S rotates. The cylinder is divided by the walls W W into two compartments, and the central portion of the piston, which is cylindrical, rotates or oscillates air-tight between the two walls. From the central portion of the piston project the two blades or tongues P P on which presses the working fluid or gases entering by the inlet ports I I, which are always open to the engine cylinder when the instrument is in use and the tap open. The fluid pressure tends to rotate the piston in the direction of the arrows. Two holes A A drilled in the end of the cylinder are always open to the atmosphere, and thus provide a way of escape for the air on the other side of the piston blades. The motion of the piston is opposed by the spiral spring, which becomes twisted. The rod or spindle S S, Figs. 244 and 245, on which the piston P is fixed, also carries at one end outside the cylinder the double coiled spiral spring, Fig. 245, and on the other end the pencil holder or radial arm is clamped. The ball on the cross wire at end of the spring fits into the V slot in the piston rod, which is turned so that two steel studs M M

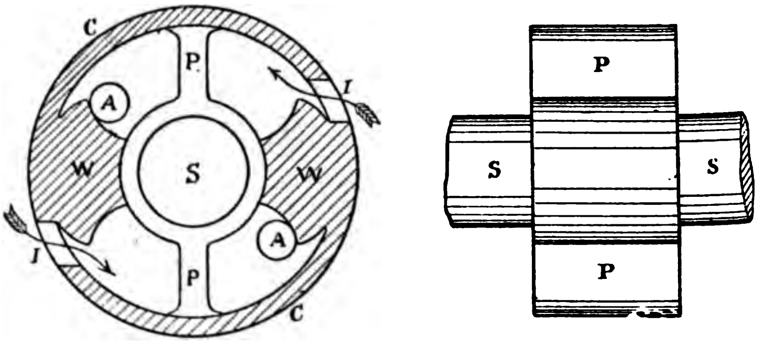

FIG. 244—WAYNE INDICATOR (SECTION OF CYLINDER AND PISTON).

fit the holes D D in the spring plate. The spring is held in position by a screw cap which fits into the V slot. The pencil point on the other end of the piston rod is made to describe an arc, and the diagram is traced on the paper which is carried on an aluminium frame with circular clips, so as to bend the paper into a cylindrical surface concentric with the spindle S S. As in Watt's original indicator, the paper frame simply slides to and fro in a straight line synchronously with the engine piston.

The turning effort or torque acting on the piston is directly proportional to the fluid pressure. The resisting moment or torque due to the torsion of the spring is proportional to the angle of twist, that is, to the length of arc traced out on the paper whose surface is cylindrical. Since for equilibrium the applied torque must equal the resisting torque, it follows that the height of the diagram, when the paper is removed from the slide and flattened out, is directly proportional to the fluid pressure, and hence the diagram may be dealt with in the same way as those from other indicators.

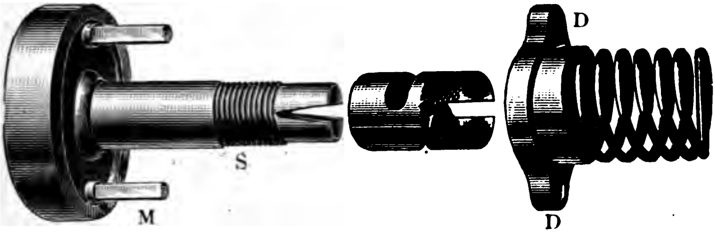

FIG. 245.—THE WAYNE PISTON ROD AND SPRING (FULL SIZE).

The main advantages of the Wayne indicator are :—

1. Absence of link motion to multiply the movement of the piston, so that the troubles and errors due to inertia are greatly reduced.

ary, there is no trouble due to
equence of its being forced side-
s, and the piston friction is there-
arings only.

2 \\ 2

3. The absence of the motion against gravity.

4. The spring being outside the cylinder is not greatly heated to change its elasticity, and it may be removed and replaced by another in less than a minute, without any trouble and without otherwise touching the instrument.

The weak point is in the reciprocating motion of the light sliding frame of aluminium, the bearing surface of which is liable to wear loose, giving back-lash unless provision is made to take up the wear. Professor F. W. Burstall eliminated the error due to inertia, by driving the slide from the reducing gear by means of a steel wire passing round a pulley on each side of the frame. The pencil friction is also reduced by replacing the paper by a thin sheet of mica thinly coated with smoke.*

The Wayne indicator is particularly useful in taking diagrams from gas and petroleum engines, and stands a good deal of rough usage.

HOW TO TAKE AN INDICATOR DIAGRAM.

We are now in a position to understand **how to use the indicator** to take an indicator diagram from the cylinder of an internal combustion engine.

See that the indicator is clean and in good working order. Unscrew the cover of the indicator cylinder and remove the piston. Clean the cylinder and piston, and lubricate them thoroughly with the best cylinder oil. The joints and pivots of the link motion and the paper drum should move very freely without any looseness or back-lash. Oil these with special oil, like refined neatsfoot, supplied with the instrument. Next select a spring suitable to the maximum pressure of the explosion, and if the engine runs at a high speed use a stiffer spring. For modern gas engines using high compression, the spring should be from No. 100 to 200, or as marked $\frac{1}{100}$ and $\frac{1}{200}$, so that a pressure of 100 or 200 lb. per square inch will raise the pencil 1 inch. The height of the indicator diagram should not be more than $1\frac{3}{4}$ or 2 inches, so that the pencil is not driven off the paper drum by an occasional violent explosion, and undue oscillations are not produced in the explosion line of the diagram. Put, as safety stop, a little brass tube on the piston rod of the indicator inside the spring, to strike against the cylinder cover and so prevent undue compression of the spring beyond a suitable range, and thus protect the mechanism from injury. This precaution is especially necessary when light springs of $\frac{1}{8}$, $\frac{1}{10}$ or $\frac{1}{12}$ are used, to take diagrams giving only the pumping strokes, exhaust, suction and early part of the compression. When putting in the spring, make sure that it and piston are tightly screwed together and fixed on the cylinder. The pencil lead should be sharpened. Then screw the indicator into the hole drilled for it near the end of the engine cylinder over the clearance space.

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* See *Proc. Inst. Mech. Engineers*, April 1898.

Attach the cord to the reducing gear on the engine piston, and adjust the length of the cord so that the drum does not strike the stops at either end of its motion, and yet have as long a range as possible. Provide a light hook for disconnecting the cord when not taking a diagram. Wrap a sheet of paper closely on the drum, and tighten its ends under the clips.

Next, adjust the screw of the pencil movement against the stop, so that the pencil only just touches the paper, and the pressure is enough to make a distinctly visible but not heavy mark on the paper. This precaution saves the fine pencil point, and prevents excessive friction that would cause errors in the diagram.

Open the indicator cock, and the pressure of the gas from the engine cylinder forces the indicator piston up against the spiral spring or allows the latter to press it down, thus causing the pencil to play up and down. This warms the instrument, indicates the highest and lowest pressures we may expect, and thus affords a guide to the proper strength or scale of spring. If the cord is hooked on, giving the paper drum the to-and-fro motion of the piston at the same time that the cock is open, and the pressure of the gases in the cylinder allowed to act on the indicator piston, the pencil plays up and down. Now, by the handle on the sleeve carrying the

link motion, bring the pencil round to touch the paper very gently during one explosion and complete cycle of the engine. This gives a closed curve like P Q R S T S′ P, Fig. 246, called an indicator diagram.

Shut the indicator cock and the indicator pencil remains at rest, but when the paper drum is moved underneath it a horizontal line is traced out. This is called the *atmospheric line*, T S′, since it represents the atmospheric pressure on the indicator piston. Its length is the travel of the piston on a small scale. Detach the cord or move the detent spring to make the pawl go into gear with the ratchet teeth, and hold the drum at rest.

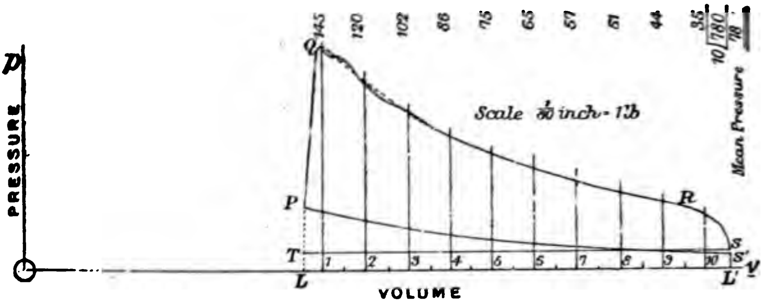


FIG. 246.—GAS ENGINE INDICATOR DIAGRAM (HALF SIZE).

Take the paper off the drum and replace it by a fresh sheet.

While this is being done, the number of explosions and revolutions per minute of the engine should be counted, and marked on the indicator diagram with the scale number of the spring used, the diameter of engine cylinder and length of stroke. It is also important and convenient for reference, to note on a corner of the card the date, hour, and number of the diagram if one of a series from any particular engine; also the load on the engine.

It will be observed that the indicator diagram is the result of two motions: the *vertical motion* of the pencil due to the pressure in the engine cylinder, and the *horizontal motion* of the paper which represents the *travel* of the motor piston.

Hence any point on the curve indicates the *pressure* in the cylinder corresponding to that position of the piston given by the horizontal distance along the atmospheric line.

By measuring the vertical distance between the top curve and the lower one with the scale of the spring used, we find the pressure, in pounds per square inch, of the working agent in the cylinder on the piston at every point throughout the stroke.

If the mean height of an indicator diagram is 0·5 inch, and the scale is $\frac{1}{150}$, that is, a pressure of 150 lb. per square inch on the indicator spring will give a height of 1 inch, then the *mean* or average effective *pressure* is 0·5 × 150 = 75 lb. per square inch, that is, the difference between the mean pressure during the compression and explosion strokes; neglecting for the present the pressures during the exhaust and charging strokes, which are too small for indication on the same scale.

Measure a distance below the atmospheric line equal to 14·7 lb. per square inch or the barometer reading at the time to the same scale, and the line O v drawn through this point parallel to the atmospheric line, is the line of no pressures or the *vacuum line.* Heights above this represent *absolute* pressures.

THE INDICATOR DIAGRAM.

Now **what does this indicator diagram tell us** about the operations in the gas engine? During what is called *a complete cycle* of operations the working substance, in the cylinder, undergoes a series of changes in volume and pressure, and is brought back exactly to its initial state whilst the indicator pencil has been tracing this *closed curve.* We must bear in mind that, in the engine from which the diagram, Fig. 246, was taken, one end of the cylinder is open, exposing one side of the piston continually to the pressure of the atmosphere. The various pressures exerted by the gas in the cylinder, on the other side of the piston, in pounds per square inch of its area, are given by the diagram, and can be measured on it by the indicator scale.

It will be most convenient to *find first the effective work done on unit area of the piston*, and this multiplied, by the cross-sectional area of the piston acted on, will be the total work done on it by the gas during a complete cycle.

Let O *v* be the vacuum line ; heights above this represent absolute pressures in pounds per square inch, whilst distances along it, measured from O, represent lengths of cylinder in feet occupied by the gases. When the piston is at the end of its stroke, O L is the length of cylinder having volume equal to the clearance space including passages, and is about two-thirds of L L′ the travel of the piston. This is measured independently of L L′, which is twice the length of the crank.

The volume of the clearance space or combustion chamber is determined by the quantity of water which fills it when the piston is at the inner dead point and the valves are all shut.

Suppose now, to start with, the indicator pencil is at T, and L T represents a pressure of 14·7 lb. per square inch, that is the atmospheric. As the piston moves from L to L′ the charge is drawn in, and the connecting cord pulls round the paper drum underneath the pencil which marks the line T S′. The pencil scarcely moves, as the pressure is nearly atmospheric on both sides of the piston, and therefore no appreciable work is done. The gas and air inlet ports of the cylinder are now closed, and in the return stroke the piston compresses the charge ; whilst the spring inside the paper drum pulls it back, and the pencil rises with the pressure along the curve S′ P.

Here the work done by the piston on the working substance is shown by the area L′ S′ P L. During this return stroke the piston has been assisted in compressing the charge by pressure of the air on its other side, and L′ S′ T L is the work done on the piston by the atmospheric pressure at the open end of the cylinder. The difference S′ P T is the work done *by* the engine itself *on* the gases.

At P the charge is fired, and the pressure suddenly rises to Q, the burning gases expand, driving forward the piston and the cord from the reducing gear to the indicator again pulls round the paper-covered drum. The sudden rise in pressure to Q causes a tremor in the spring, which we have corrected by the dotted line Q R.

When the pencil is at R the exhaust valve opens, allowing the gases to escape, and the pressure in the cylinder falls more quickly. Still the gas is doing work on the piston to the end of the stroke at S. The pressure of the atmosphere on the other side of the piston has been a retarding force, which was overcome, and above this the work done *by* the gases *on* the piston is represented by the area T P Q R S S′.

During the back stroke the exhaust valve is open along S T, and the piston does work expelling the products of combustion, but is assisted by the atmospheric pressure on its other side, so we can only give the engine credit for the work represented by the very small area S T S′ bounded by the lines S T and T S′, which are nearly coincident.

The pencil is back again at T, and the products of combustion occupy the clearance space, O L, just as when we started.

Neglecting for the moment (see p. 371) the small area S S′ T, we see that the area T P Q R S S′ expresses the work done by the burning gases in moving the piston, and T P S′ is the work done by the piston in compressing the charge above atmospheric pressure; therefore the difference, namely, *the area* P Q R S, *represents the effective work done on the piston, per square inch of its area, by the burning gases in the cylinder during one explosion or a complete cycle of the engine.*

Hence the area of the indicator diagram, or its mean height multiplied by its length, represents $p\,l$ foot-lb. of *work done* by the gases in the cylinder on each square inch of the piston, i.e. *the mean pressure in the cylinder,* p *lb. per square inch multiplied by* l *feet the travel of the piston or twice the length of the crank.*

From this it is evident that the indicator diagram from an engine enables us **to calculate the work done on the piston by the working agent** from measurements of p, which may be made in either of two ways :

1st, measure the average height of the diagram directly;

Or, 2nd, measure the area of the diagram and divide by its exact length.

1. The simplest approximate method, and the one which engineers use most frequently, is to measure the mean or average pressure from the indicator diagram as follows:— Divide the distance L L′ into ten equal parts, bisect these, and from the points of bisection draw ten equidistant lines at right angles to the atmospheric line, as in Fig. 246. With a scale of inches and tenths, or better still a stiff *strip of paper* with straight edge, measure or lay off successively the lengths of these lines intercepted by the closed curve P Q R S. Add these lengths together and divide by ten gives the average height of the diagram in inches, and this multiplied by the scale number of the spring used in the indicator cylinder gives the mean effective pressure *p* pounds per square inch driving the piston during the compression and working strokes.

In Fig. 246 the mean height of the actual indicator diagram is 0·975 inch, and the scale number of the spring used gives a compression of 1 inch for 80 lb. per square inch, therefore the mean pressure is 0·975 × 80 = 78 lb. per square inch. The effective pressure at each division of the stroke is given in Fig. 246, as read off the indicator scale directly by means of a small magnifying glass.

As this operation is likely to disfigure a diagram, these measurements are sometimes made on tracings of the original diagram. Here errors may creep in, and the addition of a series of lengths which are only approximations may also lead to slight inaccuracy, especially when the diagram is a small one from a strong indicator spring.

2. **Amsler Polar Planimeter.**—The polar planimeter, invented in 1856 by Prof. Amsler, of Schaffhausen, Switzerland, is now generally used to measure the area and height of indicator diagrams where great accuracy and saving of labour is desired.

One form of this planimeter, shown in Fig. 247, is specially arranged to give at once the average height from an indicator diagram in fortieths of an inch.

It consists of two bars, the radius bar P K and the pole-arm F K, hinged together at K so as to have perfect freedom of motion in one plane. The needle point P in the radius bar is kept fixed, whilst the tracing point F on the pole-arm is carried *clockwise* (in the direction the hands of a clock go) round the boundary of the diagram. The roller wheel D fixed to the pole-arm partly rolls, and slips only when the tracer moves exactly in the direction of the axis of the arm. After moving the tracer F completely round the diagram back to the starting point, the area is registered by the revolving wheel and vernier.

This roller wheel is very delicate, especially the rolling surface of the rim, which should be kept true.

This instrument has also a horizontal wheel G which registers the tens, the roller wheel D tenths and hundredths, whilst the vernier gives the third place of decimals. The sliding bar A or pole-arm carrying the tracer F may be varied in length by means of the sleeve H which slides along it, for the purpose of recording the area in different units, as square inches and square centimetres. The vertical lines on this sliding bar have the various units marked alongside.

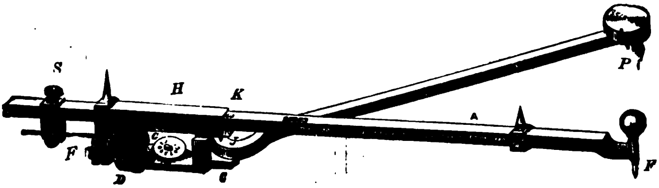


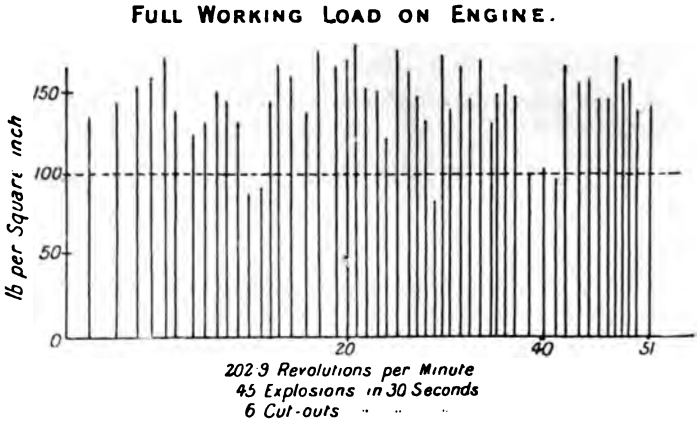
FIG. 247.—THE AMSLER PLANIMETER.

The instrument is set *for measuring areas* by adjusting the sleeve H so that the mark J on the inner end of it at K is exactly opposite the division on the sliding bar corresponding to the particular unit in which the area is desired. Then clamp the sliding bar by the screw at S, and proceed as above.

The accuracy of the instrument may be checked beforehand by moving the tracing point round a known rectangle, and comparing the indicated value with that already calculated.

Next, *to read the* **mean height** *at once from an indicator diagram.* Loosen the clamp screw S and adjust the two steel points, on the upper side of the bar A, to the extreme points of the diagram, measured on a line parallel to the atmospheric line, by inverting the instrument so that the two points take in the exact length of the diagram, then clamp the bar by the screw S.

Having thus set the sliding bar, place the planimeter on a flat even surface, as a sheet of drawing paper. Sink the needle point P into the paper at a convenient distance outside the diagram, and place a weight upon the bar to keep it in its place. Start with the point of the tracer F, Fig. 247, on any point, say S, of the diagram, Fig. 246, with the arms of the planimeter nearly at right angles. Adjust the wheel and vernier to zero. The tracing point F is carefully carried clockwise round the diagram on the curve S P Q R, returning to the starting point S.


FULL WORKING LOAD ON ENGINE.

202·9 Revolutions per Minute
45 Explosions in 30 Seconds
6 Cut-outs " "

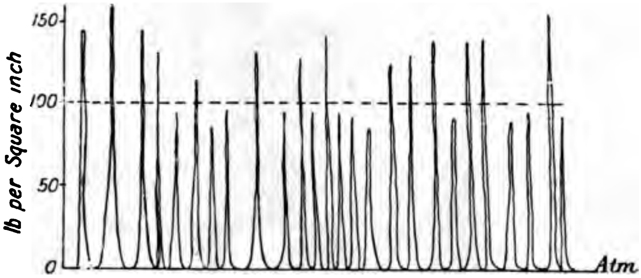
Fig. 248.—Maximum Pressure in Oil Engine Cylinder (½ minute).

Now the figures on the horizontal wheel G stand for hundreds, the roller wheel gives tens, with the small divisions units, and the vernier decimals.

The reading is the *mean height of the diagram* in fortieths of an inch. Therefore divide by 40 to find the mean height in inches, and this quotient multiplied by the scale number of the spring gives the *mean pressure* on the piston in lb. per square inch.

When the indicator pencil is kept in contact with the paper for several seconds a number of indicator diagrams are traced, and usually these are different in height, so that there is a **variation in the mean pressure**, measured from several diagrams of consecutive explosions. Fig. 248 shows the height of the explosion lines traced on a sheet of paper on the indicator drum as it was turned slowly by hand under the indicator pencil during half a minute. The scale number of the spring was 120, so that the maximum pressure of each explosion can be found directly. Any line less than 100 lb. per square inch indicates a miss when the charge was cut off by the governor. The oil engine was working very steadily at full load and 202·9 revolutions per minute. During the half minute there were six misses and forty-five explosions of varying pressure. Fig. 249 gives fourteen explosions and twelve misses during a quarter of a minute, when the same engine was running at one-third load, and 202·8 revolutions per minute. To obtain the mean pressure **accurately** during

ONE-THIRD LOAD ON ENGINE.



202·8 Revolutions per Minute
14 Explosions in 15 Seconds.
12 Misses or Cut-outs " "

FIG. 249.—MAXIMUM PRESSURE IN OIL ENGINE CYLINDER.

all these variable explosions it is clearly not enough to take one indicator diagram at random.

A rough approximation may be found by allowing the fine tracing point of a lead pencil in the indicator to draw consecutive diagrams during half a minute, and then measure the mean pressure of all the diagrams. A *mean diagram* must be constructed from measurements of a large number of actual diagrams, plotted on square paper. For a run of several hours these operations become very tedious.

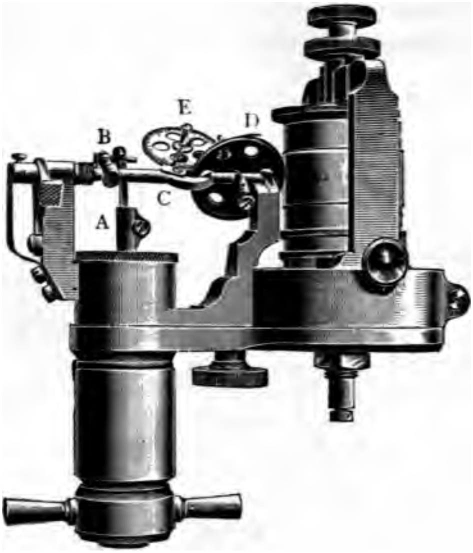


FIG. 250.—LITTLE'S INTEGRATING INDICATOR.

Integrating Indicator.—Instead of drawing all the diagrams during a run, **Little's Integrating Indicator** traces them continuously by an integrating wheel and gives an accurate record of the result. The integrating indicator thus carries out automatically the work of the ordinary Crosby indicator and Amsler's planimeter combined.

In the instrument, Fig. 250, the end of the piston rod of an ordinary Crosby indicator is attached, not to a parallel motion, but to a small slotted cross-head A connected by a small lever B to a shaft C. The vertical movement of A, the cross-head, causes the shaft to oscillate through an angle depending upon the variation of pressure on the piston, and on the strength of the spring used. On the shaft C there is mounted a wheel D and counting gear E, similar to those used in the ordinary Amsler's planimeter. Instead of a sheet of paper we have a hard brass sleeve on the drum of the indicator, and instead of a pencil rising and falling we have the wheel D increasing and diminishing its angle of inclination to the axis of the drum.

The theory of the instrument is very simple. In Fig. 251 let θ be the angle of inclination of the plane of the wheel D to the vertical axis of indicator drum. The rate of rotation of D varies as $\sin \theta = \sin \theta_1$

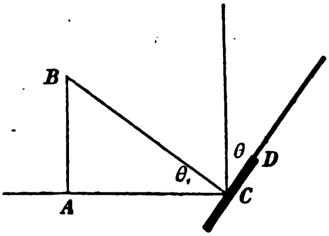


FIG. 251.

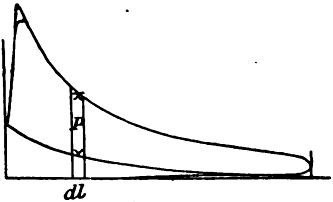


FIG. 252.

But

$$\text{Sin}\,\theta_1 = \frac{\text{A B}}{\text{B C}} = \frac{\text{vertical displacement of cross-head}}{\text{constant length of rod B C}}.$$

Therefore the rate of rotation of the wheel D varies as the pressure on the indicator piston.

Consequently, when the instrument has been through a complete cycle, the amount registered on the dial will be proportional to $\int P . d\,l$, which is the area of the indicator diagram, Fig. 252, for one complete cycle.

The instrument is so arranged that the reading, or record on the dial, is one-tenth of the area in square inches of the diagrams which would have been traced by an ordinary indicator during the same number of working strokes of the engine piston. The length of the stroke of the indicator drum must be not more than 2 inches, and is measured to the hundredth of an inch by means of a vernier.

The weak point common to rolling integrators appears to be the slip in the plane of the wheel D, which is so reduced in this instrument that the results obtained in practical use are within the limits of accuracy required in ordinary engine trials.

If, during a test for a given time, we find

R = record or difference of reading on the instrument,
N = number of working strokes of the engine per minute,

$$\text{Area of mean diagram in square inches} = \frac{R \times 10}{N},$$

Mean height in inches of diagrams is equal to

$$\frac{R \times 10}{N \times \text{length of drum stroke}},$$

and the *mean effective pressure* throughout the run is equal to

$$\frac{R \times 10 \times \text{scale number of spring}}{N \times \text{length of drum stroke}}.$$

The indicator is attached to the engine in the usual way. It is started or stopped by putting the wheel D in or out of contact with the drum. A counter is used to give N, and the time is carefully noted when the readings are taken. The instrument may be allowed to remain in action for a whole day if necessary, and is extremely useful in giving the mean effective pressure of the working fluid in the cylinder, when the explosions vary with the load under actual working conditions.

The Author *applied* **Little's Integrating Indicator** *to an oil engine* during a brake test at half load.

Scale number of the spring used was 180.
Stroke of indicator drum observed 2·02 inches.
Record on the indicator during one hour exactly 156·7.
Mean number of explosions per minute 78·5.

$$\textit{Mean effective pressure} = \frac{156{\cdot}7 \times 10 \times 180}{60 \times 78{\cdot}5 \times 2{\cdot}02} = 29{\cdot}6 \text{ lb.}$$

per square inch.

This result agrees with indicator diagrams taken before and after that interval of the trial by means of the Wayne and Crosby indicators; and was further checked by the known mechanical efficiency of the engine running steadily during several trials at the same load and speed.

A **Light Spring Diagram**, obtained by using a weak spring with a stop to limit the play of the ordinary indicator piston, records the changes in pressure during the pumping strokes, and enables us to measure the mean back pressure to be deducted from the mean-pressure to give the mean effective pressure. Fig. 253 was taken from a gas engine, running steadily at full load, making 75 explosions per minute, developing 40 brake horse-power, on a consumption of coal gas at the rate of 17·6 cubic feet per brake horse-power hour. A stiff spring of scale $\frac{1}{180}$ was used to give the full indicator diagram

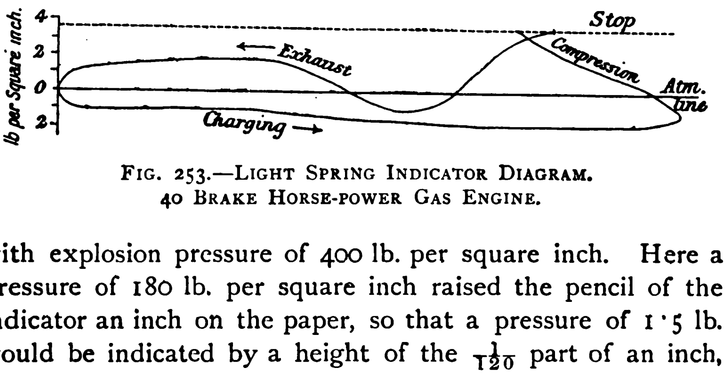


FIG. 253.—LIGHT SPRING INDICATOR DIAGRAM.
40 BRAKE HORSE-POWER GAS ENGINE.

with explosion pressure of 400 lb. per square inch. Here a pressure of 180 lb. per square inch raised the pencil of the indicator an inch on the paper, so that a pressure of 1·5 lb. would be indicated by a height of the $\frac{1}{120}$ part of an inch, which could only be observed on the diagram by the aid of a powerful magnifier. Now by using a spring of scale $\frac{1}{8}$, the lower part of the diagram is magnified and the upper part left out. The back pressure in the engine cylinder during the exhaust is thus clearly seen to fall below the atmospheric line, and rise again above it about 1·5 lb. During the charging stroke the pressure in the cylinder behind the piston is
1·5 lb. per square inch below atmospheric, so that the
ere opposes the outward motion of the piston. The
pressure is 2·5 lb. to be deducted from the mean
asured on the ordinary diagram, otherwise the

mean effective pressure *throughout the cycle will be taken too high.* Usually this mean back pressure during the pumping strokes only amounts to 1 lb. or 1·5 lb. per square inch.

The effect due to the resistance offered by the ports, passages and pipes to the burnt gases escaping, and the fresh charge coming in, is also seen at a glance on Fig. 253 by the deviation of the curves from the atmospheric line. Throttling of the incoming charge causes vacuum during the suction or inhaling stroke.

Pump Diagrams.—In order to find the work spent in *friction* of the mechanism and preparation of the charge for ignition, **Indicator Diagrams** must also be taken from the separate **Pumps** driven by the gas engine, to compress the charge into the working cylinder and to force air through the combustion chamber for scavenging purposes.

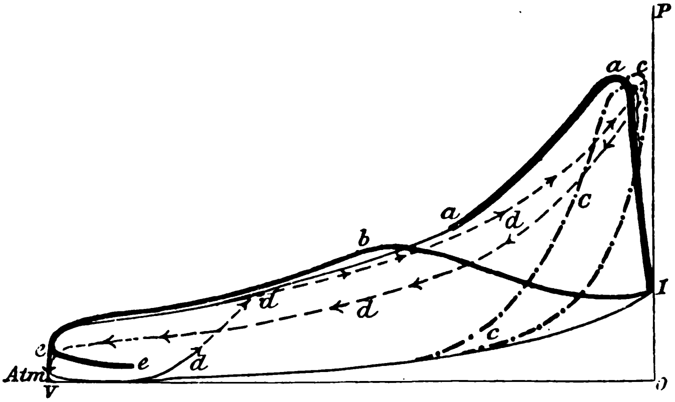


FIG. 254.—TYPICAL INDICATOR DIAGRAMS.

I *a a* good ignition, normal diagram ; I *b e* late ignition ; *c c* pre-ignition ; *d d* back-firing ; *e e* exhaust back pressure.

The **Forms** of indicator diagrams taken from the internal combustion engine tell the behaviour of the working fluid in the cylinder, and reveal defects in the timing of ignition, valve setting and general action. A few examples will illustrate some of the points learned by a glance at a diagram. A vertical ignition line, I P, may be caused (1) by imperfect adjustment of the length of cord from the reducing gear, so that the indicator paper drum comes against the stop, the diagram is cut short, and the whole stroke of the piston is not given by the motion of drum; or (2) the ignition of the charge may be too early since the maximum pressure is reached, the heat of combustion is generated, and part lost to the cylinder walls *before* the piston begins its working stroke. Besides loss of heat, there is also shock to the mechanism.

Better results are obtained by igniting slightly later, in such a way that the ignition line instead of rising straight up is inclined a little forwards like I *a a*, giving a good normal diagram for steady working, complete combustion and greater economy. The maximum pressure should be reached within the first tenth of the forward stroke.

Too late ignition, shown by a line with a greater forward inclination than I *a*, is not good for economy, although the engine may run steadily; and extremely late ignition or retarded combustion like I *b e* is very uneconomical of fuel, the rate of propagation of the flame throughout the charge is slow compared with the piston velocity, and the gases are only partially burned when allowed to escape by the exhaust. A charge too poor in gas for the given compression burns slowly in this way, and requires higher compression or more gas for the quantity of air admitted.

On the other hand, *too early* or *pre-ignition* like *c c c* due to (1) the cylinder becoming too hot, or to (2) very high compression, tends to stop the engine, and may lead to scoring of cylinder as well as shocks to the mechanism.

Back-firing or explosion during charging, caused by smouldering exhaust gases or overheated valves, and sometimes in the early part of the compression stroke *d d d*, opposes the piston's motion by the pressure indicated along the curve traced in the direction of the arrows.

Excessive *back-pressure*, *e e*, during exhaust may be due to the exhaust valve and passages being too small, or to extra resistance offered by obstructions in the exhaust pipe and silencer.

The compression line VI should rise in a curve as shown, getting steeper towards the top at I. A straight compression line indicates **leakage of gas past the valves or piston** in a gas engine, and may also be due to condensation of the heavy oil vapour by the pressure in a petroleum engine.

When the **cylinder liner is worn oval** so that there is leakage of gas past the piston, indicator diagrams traced in the order *a, b, c, d,* Fig. 255, are obtained as the cylinder becomes heated. These indicator diagrams were taken by the Author from a gas engine cylinder which was worn about an eighth of an inch oval in a diameter of 9·5 inches. During compression and explosion there was a puff of gas felt escaping and whistling past the piston sufficient to blow away the lubricating oil, so that after a run of half an hour under a brake load, the engine stopped due to the piston seizing through imperfect lubrication. The leakage diminished during the run as the piston was heated up. Here the **effects of leakage** are obvious:—the compression is reduced, the ignition is late, and the combustion retarded, the maximum explosion pressure never realised, the expansion curve flattened, the mean effective pressure only 48 lb. per square inch, the lubricating oil blown out of the cylinder, and finally the engine pulled up by overheating and seizing of the piston.

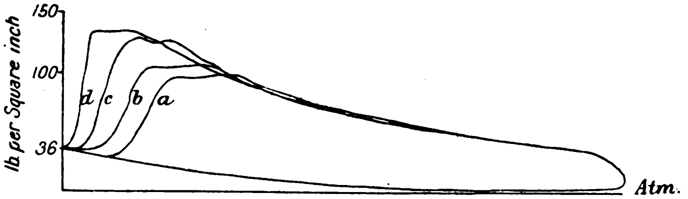


FIG. 255.—EFFECTS OF LEAKAGE PAST PISTON.

Mean effective pressure 48 lb. per square inch.

The result is an excessive consumption of gas, and only small power generated. With a load of 8 brake horse-power, at 198 to 194 revolutions per minute, the gas consumption in this modern gas engine was at the rate of 402 cubic feet per hour, that is, 50 cubic feet per brake horse-power hour! The effective heating value of the coal gas as used in the engine was 600 B.Th.U. per cubic foot.

POWER.

We have now to consider the measurement of the **power** of an engine.

By *power* we mean the *rate of doing work*, which is measured by the amount of work done in a unit of time. In order to determine the *power* or *activity* of any agent, we have to make two measurements, viz. a measurement of *work*, and a measurement of the *time* during which the work is done, the quotient $\frac{\text{work}}{\text{time}}$ is the power.

The term "power" must be carefully distinguished from "force." Unfortunately, in the older books on mechanics the word "power" was frequently used to denote a force, and this has given rise to a good deal of confusion.

The practical unit of power, introduced by James Watt, and called

One horse-power = 33 000 **foot-lbs. per minute,**

or,

„ „ = 550 **foot-lbs. per second.**

The horse-power is commonly adopted by British engineers in measuring the *rate of doing work.* Watt found, from direct experiments, that a powerful dray horse when pulling regularly and moving slowly for eight hours a day, could do work at a maximum rate of 33,000 foot-lbs. per minute. This is the net or available power of the horse, above that expended in moving himself along. At a gallop he would not have so much power left. At a slow speed a willing horse has flexibility of effort to exert a steady enormous pull for a short time far beyond his ordinary rate of working.

To find the horse-power of any agent, we have simply to calculate, in foot-lbs., the work done by it in one minute, and divide by 33,000.

The **metric** horse-power or French "*force-de-cheval*" is 75 *kilogram-metres per second* = 542·48 foot-lbs. per second,

so that 1 British *horse-power* = 1·014 *chevaux*, and
1 *force-de-cheval* = 0·986 British *horse-power* = 736 *watts.*

The C.G.S. unit rate of working is 1 erg per second, but this is an extremely small unit.

Hence, the **unit of electrical power** is,

One watt = one ampere × one volt,

and *the watt is* 10^7 *ergs per second* = 1 *joule per second.*

746 **watts** = 1 **horse-power,**
1 **watt** = 0·7372 **foot-lb. per second,**
1 **kilowatt** = 1000 **watts** = 1·34 **horse-power.**

Therefore **the electrical horse-power** expended in a circuit and transformed into heat or mechanical energy is equal to

$$\frac{\textbf{volts} \times \textbf{amperes}}{746}$$

The **Board of Trade Unit** for electric supply = 1 **kilowatt hour**, that is, equal to the expenditure of electrical energy at the rate of

1·34 **horse-power for one hour.**

Calculation of Indicated Horse-power.—The indicated horse-power of an engine is the average rate at which work is done by the gas on the piston, as calculated from the *mean* indicator diagram, not the *maximum* obtained after a cut-out. To do this we require to know:

(1) the mean effective pressure p lb. per square inch, measured from the mean diagram after deducting the back pressure on the piston in the pumping strokes;

(2) the diameter d inches of the engine cylinder, and its area $a = 0{\cdot}7854 \times d^2$ square inches;

(3) the length of the stroke l in *feet*, or twice the length of crank; and

(4) the number n of explosions per minute when the diagram was taken.

In order to check the latter number, as well as for brake tests, we must also know

(5) the speed of the engine, that is, the number of revolutions per minute of the crank-shaft.

Then for every explosion or diagram

$p\ a$ lb. is the total mean effective pressure or force driving the piston.

$p\ a\ l$ foot-lbs. is the effective work done by the burning gas on the piston per explosion, that is, in one complete cycle of the engine or for every diagram.

Hence the formula $p\ l\ a\ n$ foot-lb. gives the work done per minute on the piston, where n is the number of explosions per minute, and

$$\textit{Indicated horse-power} = \frac{\textit{foot-lbs. per minute}}{33{,}000} = \frac{p\ l\ a\ n}{33{,}000}.$$

When several diagrams are to be worked out for the one engine, the calculation is shortened by finding the value of the constant factor $\frac{l\ a}{33{,}000}$, and this multiplied by $p\ n$ for every diagram gives the indicated horse-power.

Following this $p\ l\ a\ n$, we can roughly calculate the I.H.P. of an engine. We must be careful to select an average diagram that gives accurately the power developed by the gas in the cylinder, not for one maximum explosion alone, but during a continuous run of several hours. The maximum indicated power calculated from a single explosion during a short run may be entirely misleading until the engine gets to a steady state.

In the special case of a single-acting Otto cycle engine, from which the diagram Fig. 246 is taken, there can only be one explosion stroke in a complete cycle every two revolutions of the engine when working with full load. For ordinary loads the explosions may take place less frequently, tending to irregularity of speed.

In every case the **number of explosions** *should be counted directly, and the average taken per minute during the interval corresponding to the* **mean indicated pressure.**

Example 1.—A gas engine, having a cylinder 9 inches in diameter and 20 inches stroke, is running at a speed of 140 revolutions per minute, with an explosion every revolution, when an indicator diagram of mean height 0·8 inch is taken; the scale of spring is $\frac{1}{80}$ inch per pound pressure; find the indicated horse-power of the engine.

The mean pressure of gas = 80 × 0·8 = 64 lb. per square inch. The length of stroke or travel of piston $= \frac{20}{12} = \frac{5}{3}$ foot.

$$\therefore \text{ Indicated horse-power} = \frac{plan}{33{,}000}$$

$$= \frac{64 \times 5 \times 0{\cdot}7854 \times 9 \times 9 \times 140}{3 \times 33{,}000} = 28{\cdot}79 \text{ horse-power.}$$

—*Answer.*

Example 2.—From an indicator diagram we find the mean pressure on the piston is 80 lb. per square inch, the area of the piston is 85 square inches, and the length of crank 9 inches. Find the indicated horse-power when the engine is running at 154 revolutions per minute, and there is a complete cycle every two revolutions. Here the length of crank is 0·75 foot, and twice this, or 1·5 foot, is the length travelled by the piston in one stroke, *while work is being done on it* by the burning gas; and this occurs only every other revolution. Putting these values in our formula, we have—

$$\text{Indicated power} = \frac{80 \times 1{\cdot}5 \times 85 \times 77}{33{,}000} = 23{\cdot}8 \text{ horse-power.}$$

—*Answer.*

Exercise 1.—A gas engine, 7 inches diameter of cylinder, stroke 12 inches, is making 146 revolutions per minute, with an explosion every revolution, when a diagram is taken of 0·6 inch mean height; the scale of spring is $\frac{1}{100}$ inch per pound. What is the indicated horse-power?—*Answer,* 10·21 I.H.P.

Example 3.—Given the diameter of cylinder 11 inches, the length of stroke 18 inches, and the speed 160 revolutions per minute when the diagram Fig. 246 is taken. There is an explosion every alternate revolution. Find the indicated horse-power.

By the diagram we find the mean pressure 78 lb., deducting from this 1·5 lb. to allow for the average back pressure during the pumping strokes, when the piston draws in the charge and expels the burning gases, we get the *mean effective pressure* urging the piston 76·5 lb. per square inch.

The area of piston is 11 × 11 × ·7854, or 95 square inches. Thus the total average force driving the piston is 95 × 76·5 lb.

The length of stroke 18 inches or 1·5 foot is the distance through which the gases do work on the piston. Therefore the work done in one cycle is 95 × 76·5 × 1·5 foot-pounds. The speed is 160 revolutions per minute, and there are half this number or 80 explosions per minute, since no misses are recorded. The rate of doing work is then 95 × 76·5 × 1·5 × 80 foot-pounds per minute, hence the horse-power is

$$\frac{95 \times 76{\cdot}5 \times 1{\cdot}5 \times 80}{33{,}000} = 26{\cdot}44 \text{ I.H.P.}\text{—}\textit{Answer.}$$

Mechanical Efficiency of Engine.—Part of the gross indicated power, generated by the gases acting on the piston in the engine cylinder, is wasted in doing work against fluid resistance in the pumping strokes, and has to be deducted to find the net indicated power of the engine. Another portion of the effective indicated horse-power is spent in overcoming the frictional resistances in the mechanism of the engine itself, and the remainder, available at the crank-shaft for useful work in driving other machinery, is called the **effective horse-power** or **brake horse-power.** For a given engine, running at a constant suitable speed, the power spent in the engine friction is nearly constant at all loads, or is independent of the load, and depends upon the design of the mechanism, the smoothness, exactness of fit, and proper lubrication of the rubbing surfaces and bearings. Thus *the effective power is always less than the indicated power by the amount of power lost in the engine friction*, which is practically constant. In other words, the power spent in engine friction is the indicated horse-power developed in the cylinder to keep the engine running without load at the given speed when thoroughly lubricated. Hence the effective horse-power of a large engine for any load *at constant speed*, may be found *approximately* by taking the indicated horse-power at that load, and deducting the indicated horse-power of the engine when running light at the same speed. *The ratio of the effective or brake power to the indicated power is the mechanical efficiency of the engine.*

$$\textbf{Mechanical efficiency} = \frac{\textbf{brake horse-power}}{\textbf{indicated horse-power}}.$$

Since the work absorbed in engine friction is roughly constant, the mechanical efficiency is greatest at full load, and becomes reduced for light loads. An internal combustion engine under ordinary conditions, at full working load, gives say 20 indicated horse-power and 17 effective or brake horse-power. The mechanical efficiency is then 0·85 or 85 per cent., a good average result. Here 3 horse-power is required to drive the engine itself light at that speed. For this engine, properly lubricated, the mechanical efficiency will vary with the load as follows:—

Indicated H.P.	Brake H.P.	Mechanical Efficiency.
20	17	0·85
15	12	0·80
12	9	0·75
10	7	0·70
5	2	0·40
3	0	0 00

The work lost in friction increases slightly as the load on the engine increases.

It is obviously wasteful and uneconomical to run the engine at light loads. Hence the importance of running about full load in regular working. For long continuous running gas engines work smoothly and give best results at about two-thirds to three-fourths of the load specified by the makers. Generally, under favourable conditions, the power lost in friction of a gas engine varies from 10 to 30 per cent. of the full power developed in the cylinder and called indicated horse-power.

The effective horse-power delivered at the crank-shaft is called the *brake horse-power*, because it is measured by a brake or dynamometer. In **friction-brake** *or absorption dynamometers* all the power of the engine is absorbed and wasted in friction.

A simple form of friction-brake, shown in Fig. 256, can readily be made in any workshop in a few minutes at a small cost. It consists of ropes wrapped round a brake pulley and kept apart as well as from slipping off the brake wheel by wooden cross-pieces. These should be laced to the ropes, and not fastened by screws or metal liable to touch the rim of the wheel and become excessively heated by the friction so as to burn the rope.

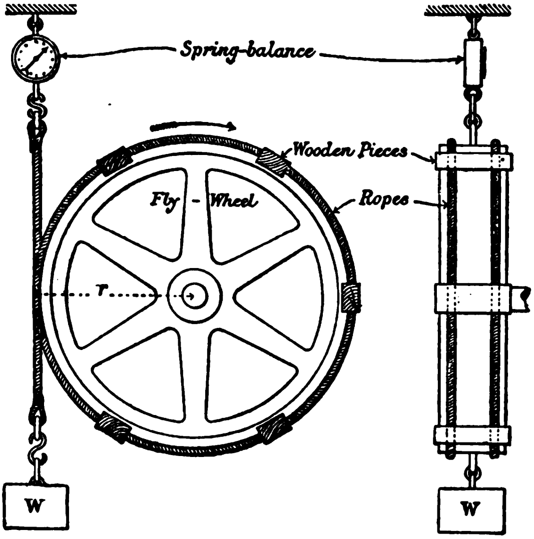


FIG. 256.—FRICTION-BRAKE DYNAMOMETER.

A leather or camel hair belt may be passed half round the wheel, with dead weights hanging on one end, and a spring balance taking the pull at the other. The load is applied by putting the weights on the end of the ropes or belt, so as to oppose the rotation of the brake-wheel, and thus to be lifted by the engine. The pull in the spring balance attached to the slack end helps the engine, but is necessary to get enough friction between the ropes and brake-wheel, and, for any given dead weight, varies slightly, due to alterations in the coefficient of friction caused by heating of the wheel and drying of the rope. A little grease or petroleum applied to the surface of the wheel keeps the frictional brake resistance steady and makes the ropes or belt work more smoothly. The readings of the spring balance must be taken frequently.

The load or resistance is adjusted by varying the weight W lb., and the pull S lb. in the spring balance changes accordingly.

The difference between the pulls on the ends of the belt or ropes W − S lb. is the net load or effective resistance of the brake, and the work done by the engine in overcoming this friction is

$$2\,\pi\,r\,(W - S) \text{ ft. lb. per revolution,}$$

where r feet is the effective radius of the brake-wheel measured from the axis of rotation to the middle of the rope or belt where the pull is applied. Thus r includes half the thickness of the rope, and the effective circumference is $2\,\pi\,r$ feet. When the brake-wheel makes N revolutions per minute the power is

$$2\,\pi\,r\,N\,(W - S) \text{ ft. lb. per minute.}$$

Hence we find

$$\textbf{Brake horse-power} = \frac{2\,\pi\,r\,N\,(W - S)}{33{,}000}.$$

In other words, *the difference of the pull at the two ends of a rope or belt on a pulley, multiplied by the velocity of the rim in feet per minute, and divided by* 33,000, *gives the horse-power either absorbed or transmitted by the rope or belt.*

Again, the difference of the pull in the rope multiplied by the radius of the pulley, $(W - S) \times r$, is the total turning moment or *torque* T necessary to overcome the friction. Also at the speed of N revolutions per minute $2\,\pi\,N$ *radians* are turned through per minute; and $\frac{2\,\pi\,N}{60}$, the number of radians turned through per second, is usually called ω the angular velocity. The ratio π is 3·1416.

Thus the work done per second is $\omega\,T$, and the

$$\textbf{Brake horse-power} = \frac{\omega\,T}{550}.$$

Strap brakes may be applied to the two fly-wheels of engines, and with good metal in the wheels the power may be absorbed up to about 50 horse-power. However, to avoid "bursting" of the fly-wheel, a special brake pulley is commonly used with flanges on the rim, forming a channel inside the wheel for the cooling water. During a test a Simplex gas engine developed 575 effective horse-power, which was absorbed by a large rope brake coupled direct to the main shaft, and cooled internally with circulating water.

A **hydraulic brake** used successively by Hirn and Joule, consisted of a paddle wheel with vanes fixed on the shaft and bafflers on the casing. The moment of resistance tending to turn the casing round the shaft was measured by weights hung on the casing. (*See* page 393).

In 1877 William Froude invented a water friction brake for measuring the power of marine engines by paddle vanes and baffles which gave great resistance. The work was absorbed in the agitation of water in the brake-wheel or *turbine reversed.*

For large powers Prof. Osborne Reynolds has designed and used* a modification of the Froude hydraulic brake, which gives the greatest resistance, with constant pressure in the interior of the brake-wheel, and the resistance is regulated by the quantity of water in the wheel. The power of the engine is spent in churning water by a reversed turbine wheel fixed on the driving shaft, whilst the water enters at the centre and is passed radially through the wheel to the casing of the turbine. The radial centrifugal force of the water in the pockets and passages urges the wheel and the casing of the turbine in opposite directions, tending to make the latter turn. This turning moment exerted by the engine shaft on the turbine wheel, is measured by weights suspended on a lever fixed to the casing of the turbine to prevent it from turning. The work is spent in heating the water, and by observing the quantity of water passing through the wheel and its rise in temperature, Professor Reynolds measured the mechanical equivalent of heat (page 395).

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* See *Proc. Inst. Mech. Engineers*, July 1877; *Proc. Inst. C.E.*, *Vol.* 99, 1889-90; *Philosophical Transactions of the Royal Society*, 1897.

In order to avoid confusion it is desirable that every engine should be sold and guaranteed upon the actual or effective horse-power which it will give at the belt pulley, as measured by a friction brake or absorption dynamometer on the crank-shaft, when running steadily for *several hours or days* continuously under ordinary service conditions at normal speed, and using fuel of known heating value. (*See also* page 612).

Example.—A National gas engine having cylinder 10 inches diameter by 18 inches stroke, gave the following data under test at full load (page 254). Mean speed 170·3 revolutions per minute; mean number of explosions 82·5 per minute; mean pressure from the ordinary indicator diagrams 90·6 lb. per square inch, and from the light spring diagrams of exhaust and charging strokes 1 lb. per square inch, leaving the mean effective pressure 89·6 lb. per square inch. The circumference of the fly-wheel was 12 feet 7⅝ inches, and the diameter of the brake rope 1·25 inch, so that the total effective circumference of the brake-wheel was 12·96 feet, the brake weight, 407·5 lb., and the mean reading of the spring balance giving the pull at the other end of rope 63·9 lb. The total gas consumption in one hour was 371·5 cubic feet, and the net heating value of the gas as used by the engine 630 B.Th.U. per cubic foot.

Find (*a*) the indicated horse-power, (*b*) brake horse-power, (*c*) mechanical efficiency, (*d*) the consumption of gas per horse-power hour, and (*e*) the percentage of heat energy supplied which is converted into work done on the piston.

(*a*) The sectional area of the cylinder $= 0{\cdot}7854 \times 10 \times 10 = 78{\cdot}54$ square inches; and the length of stroke is 1·5 foot;

$$\therefore\ \text{Indicated H.P.} = \frac{89{\cdot}6 \times 78{\cdot}54 \times 1{\cdot}5 \times 82{\cdot}5}{33{,}000} = 26{\cdot}4.$$

(*b*) The resistance overcome at the brake $= 407{\cdot}5 - 63{\cdot}9$, or 343·6 lb., and

$$\text{Brake H.P.} = \frac{12{\cdot}96 \times 170{\cdot}3 \times 343{\cdot}6}{33{,}000} = 23.$$

(*c*) The power lost in friction of the mechanism is only 26·4 − 23 horse-power, or 3·4 horse-power, and

$$\therefore \text{ Mechanical efficiency} = \frac{23 \text{ B.H.P}}{26 \cdot 4 \text{ I.H.P.}} \times 100 = 87 \text{ per cent.}$$

(*d*) The gas consumption is

$$\frac{371 \cdot 5}{23} = 16 \cdot 15 \text{ cubic feet per brake horse-power hour,}$$

$$\text{and } \frac{371 \cdot 5}{26 \cdot 4} = 14 \cdot 07 \text{ cubic feet per indicated horse-power hour.}$$

(*e*) The heat energy supplied by the gas was

$$14 \cdot 07 \times 630 = 8864 \text{ B.Th.U. per indicated horse-power hour.}$$

$$\therefore \text{ Thermal efficiency} = \frac{\text{heat turned into indicated work}}{\text{heat supplied in the gas}}$$

$$= \frac{2545}{8864} \times 100 = 28 \cdot 7 \text{ per cent.}$$

The distribution of heat in the engine is given with the results of the trial, page 255.

Exercise 1.—A brake-wheel on the crank-shaft of an engine is fitted with a rope brake, and runs at 180 revolutions per minute. If the diameter of the wheel to the centre of the rope is 6 feet, the dead load 140 lb., the pull on the spring balance 15 lb.; calculate the brake horse-power. *Answer* 12·9 B.H.P.

Exercise 2.—In a full load trial of a Crossley gas engine, running at 169·35 revolutions per minute when the indicator diagrams, Fig. 66 and 67, page 134, were taken, giving a mean effective pressure of 83·5 lb. per square inch, the load on the rope brake was 346 lb., and the mean reading of the spring balance 57 lb., and 465 cubic feet of gas per hour was used by the engine. The circumference of the fly-wheel for the brake was 17 feet 3¾ inches, and the circumference of the rope 3⅛ inches. Find (*a*) the effective circumference of the brake-wheel in feet; (*b*) brake horse-power; (*c*) indicated horse-power; (*d*) mechanical efficiency; and (*e*) the percentage of heat converted into work done on the piston.

Answer.—(*a*) 17·57 feet; (*b*) 26·1 brake horse-power;

(*c*) 30·4 indicated horse-power; (*d*) 85·5 per cent; (*e*) 27·7 per cent.

Exercise 3.—In a brake test at half load, in the oil engine cylinder 10·75 inches diameter and 14 inches stroke, there were 78·5 explosions per minute, having a mean effective pressure 29·6 lb. per square inch. The diameter of the brake-wheel, as in Fig. 256, is 63·75 inches, and of the rope $\frac{5}{8}$ inch. During the run of one hour the brake weight was 81 lb., the mean reading of the spring balance 14 lb., and the average speed 157 revolutions per minute. Calculate (*a*) the effective circumference of the brake-wheel in feet, (*b*) brake horse-power, (*c*) indicated horse-power, (*d*) power lost in engine friction, and (*e*) mechanical efficiency of the engine. *Answer*: (*a*) 16·85 feet; (*b*) 5·37 brake horse-power; (*c*) 7·43 indicated horse-power; (*d*) 2·06 horse-power; and (*e*) 0·72 or 72 per cent.

Brakes on Vehicles.—Friction or band brakes are applied to the wheels of vehicles to stop them. If the weight carried by the two brake-wheels of a motor car is $\frac{1}{2}$ ton, that is, 1120 lb.; and the **coefficient of friction** of the rubber tyres on common roads is 0·6; then the frictional resistance or adhesion of the tyres on the road is $0·6 \times 1120$, or 672 lb., which is the greatest brake resistance or tractive force that can be applied without causing the wheels to slip or skid on the level road. Again, the loaded vehicle, weighing 1 ton and going at 10 miles an hour, that is $\frac{10 \times 5280}{60 \times 60} = 14·67$ feet per second, has a store of 7480 foot-lbs. of work to be absorbed before the motion is stopped on the level (page 388). When the driving power ceases to act, and the brake of 672 lb. resistance is applied to the wheels, the vehicle can be stopped within the distance $\frac{7480}{672}$, or 11·1 feet. This distance will be reduced by the road resistance to traction, which is, for

	lbs. per ton.
pneumatic rubber tyres on common roads about . . .	40 to 60
iron-tyred wheels on good hard smooth surface . . .	20 to 40
,, ,, ordinary macadam ,, . . .	45 to 100

101 57